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Hot-wire surveys in the vortex wake downstream of a three-percent fighter aircraft model at high angles of attack

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Monterey, California: Naval Postgraduate School

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THESIS

HOT-WIRE SURVEYS IN THE VORTEX WAKE DOWNSTREAM OF A THREE-PERCENT FIGHTER AIRCRAFT MODEL AT HIGH ANGLES OF ATTACK

by

William David Frink Jr

December 1990

Thesis Advisor: Sheshagiri K. Hebbar
Co-Advisor: Max F. Platzer

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A low-speed wind tunnel investigation was conducted to examine the vortex wake downstream of a three-percent scale model of the YF-17 lightweight fighter prototype at high angles of attack. The study was in support of NASA Ames Research Center's wind tunnel investigation of a full scale F/A-18 as part of NASA's High Alpha Technology Program. Smoke flow visualization was used to locate the downstream vortex wake. Hot-wire surveys were taken through the vortex at two stations; one directly aft of the model and the other at a station three model lengths downstream of the model. The effect of adding a fence to the leading edge extension (LEX) was studied. Power spectra from the hot-wire were recorded for the survey station directly aft of the model. Results show that peak turbulent fluctuation at this station occurred at 25 degrees angle of attack, lateral turbulent fluctuation greatly diminished at the far downstream

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Hot-Wire Surveys in the Vortex Wake Downstream of a Three-Percent Fighter Aircraft Model at High Angles of Attack

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ABSTRACT

A low-speed wind tunnel investigation was conducted to examine the vortex wake downstream of a three-percent scale model of the YF-17 lightweight fighter prototype at high angles of attack. The study was in support of NASA Ames Research Center's wind tunnel investigation of a full scale F/A-18 as part of NASA's High Alpha Technology Program. Smoke flow visualization was used to locate the downstream vortex wake. Hot-wire surveys were taken through the vortex at two stations; one directly aft of the model and the other at a station three model lengths downstream of the model. The effect of adding a fence to the leading edge extension (LEX) was studied. Power spectra from the hot-wire were recorded for the survey station directly aft of the model. Results show that peak turbulent fluctuation at this station occurred at 25 degrees angle of attack, lateral turbulent fluctuation greatly diminished at the far downstream station, and the addition of the LEX fence shifted energy content of turbulence toward higher frequencies.

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I would like to express deep appreciation to my thesis advisor, Professor Sheshagiri Hebbar, for his unrelenting guidance, encouragement, and patience throughout this entire project. Without his kind tutelage, this research could not have been performed. My gratitude goes to my co-advisor, Professor Max Platzer, for offering me the opportunity to undertake this research.

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I. INTRODUCTION

A. BACKGROUND

Today there is a great deal of interest in high angle-of-attack aerodynamics, or simply high alpha research. High alpha investigations have important implications for military fighter aircraft supermaneuverability, and have spin-off applications to civil aircraft safety. As a result, NASA has established a High Alpha Technology Program, an intercenter program with investigations to be carried out by NASA Ames-Moffet, Ames-Dryden, Langley, and Lewis Research Centers. Canada and Australia have similar programs.

The current investigation is in direct support of the F/A-18 High-Alpha Test scheduled to begin in the 80- by 120-foot wind tunnel of NASA Ames Research Center at Moffet Field in February 1991. This investigation is the second of a series of a cooperative studies of the F/A-18 between the Naval Postgraduate School (NPS) and NASA Ames Research Center, and is a follow-on to investigations by Leedy (1988), Sommers (1989), and Cavazos (1990). This series deals with small scale wind tunnel investigations of the vortex wake of the F/A-18 aircraft at high angles of attack and is aimed at studying the interaction between the

F/A-18's leading edge extension (LEX) vortex and the vertical tail surfaces. The investigation was conducted on a small scale (3%), utilizing the NPS 32- by 45-inch low-speed wind tunnel. A model of the Northrop YF-17, the lightweight fighter prototype from which the F/A-18 evolved, served as the test model.

B. VORTEX WAKE DEVELOPMENT

This topic is of current interest in aerodynamics research and is related to the physics of vortex dynamics at high angles of attack. It has a direct bearing on the vortex/tail surface interactions leading to the buffeting of the vertical tail which reduces its fatigue life. The buffeting of the vertical tails has led to the development and implementation of a LEX fence for the F/A-18. The spectral energy content of the vortex at several angles of attack both with and without the LEX fence, as well as the data from hot-wire surveys within the burst vortex at several downstream locations will significantly add to the understanding of vortex/tail surface interactions. It must be noted that at high angles of attack, the wake flow is usually turbulent and the vortex-turbulent wake interaction is highly complicated and difficult to model.

C. METHODOLOGY

Turbulent flow, as pointed out by Bradshaw (1971), is difficult to model mathematically. He defined turbulent studies as the art of understanding the Navier-Stokes equations without actually solving them. Until recently, that is all that could be hoped for. However, even with the availability of modern digital computers and advancement of computational fluid dynamics (CFD), experimentation still underlies much of fluid mechanics, especially in the area of turbulent flow. As CFD becomes fully developed, perhaps researchers will resort to wind tunnel investigations less and less. However, experimentation will always play an integral part in understanding and validating mathematical models.

An important tool for investigating turbulent flow is the hot-wire anemometer. Hot-wire measurements give us a measure of velocity, as first put forth in "King's law" (Goldstein, 1983, p 111). With modern electronic equipment, such as anemometers, signal conditioners, and linearizers used in these investigations, a linear relationship between the instantaneous velocity passing over the hot-wire and instantaneous voltage output may be established, making calculations of mean velocities and fluctuations a much more direct procedure. In practice, during a hot-wire survey, a non-dimensional measure of mean velocity, such as mean voltage output at a point normalized by local maximum voltage output, is often used. Likewise, a non-dimensional turbulence quantity is often used -- root mean square (RMS) voltage output at a point normalized by local mean voltage output.

The YF-17 prototype model was placed in the wind tunnel at various velocities and angles of attack, and hot-wire measurements made to ascertain information about the turbulent flow (including power spectra) in the vortex wake downstream. A leading edge extension (LEX) fence was added and the hot-wire measurements were repeated.

II. EXPERIMENTAL APPARATUS

A. WIND TUNNEL

The experimental investigations were carried out in the Naval Postgraduate School (NPS) 32- by 45-inch wind tunnel [Fig. 1].

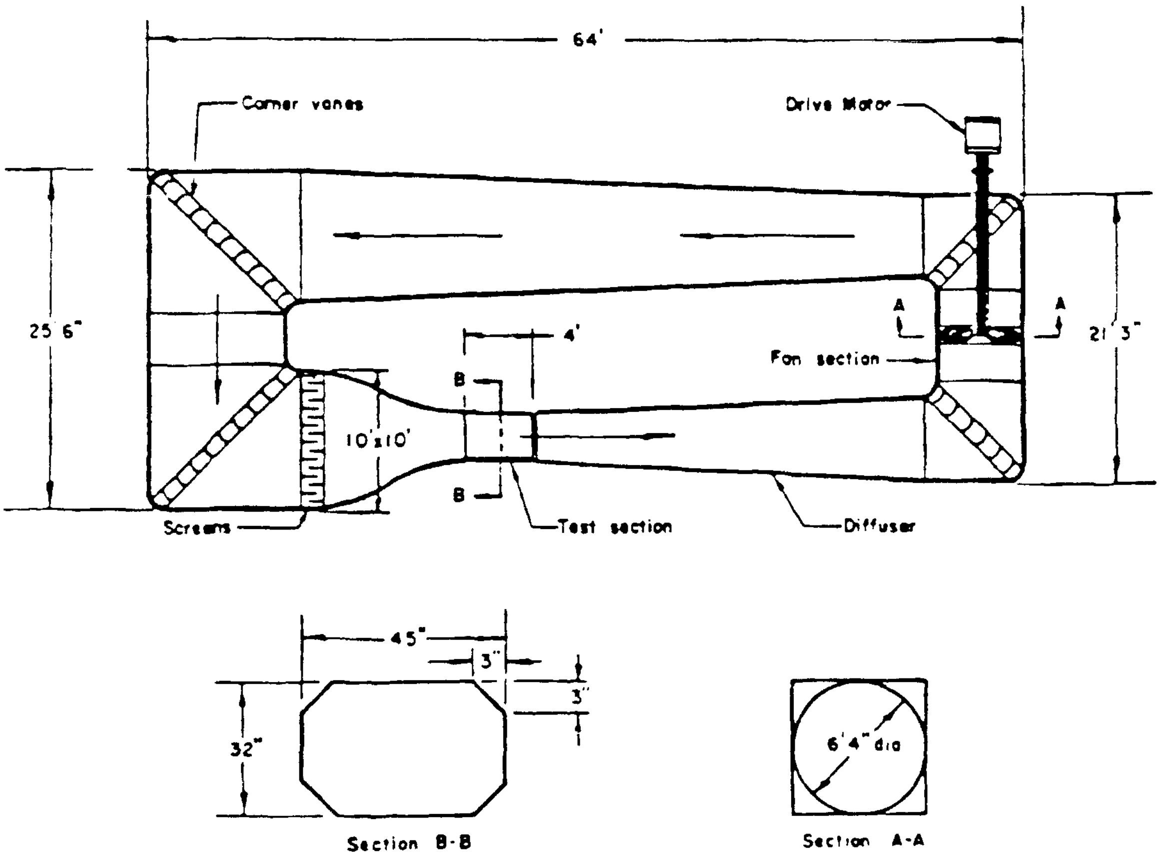

Figure 1. NPS 32- by 45-Inch Low-Speed Wind Tunnel

The tunnel is an Aerolab Development Company series 90 wind tunnel installed at NPS during the mid-1950s. It is a closed circuit, single return, horizontal flow, low-speed wind tunnel, with a contraction ratio of 10:1, maximum test section velocity of 160 knots, and a nominal freestream turbulence of 0.2% Air is circulated by a three blade variable pitch fan which is driven via a 4 speed manual transmission by a 100 horsepower electric motor. More details relative to tunnel operation and its intrumentation may be found in the Laboratory Manual for Low Speed Wind Tunnel Testing (1983, pp. 1-8).

B. YF-17 MODEL

A three-percent scale model of the Northrop YF-17 lightweight fighter prototype was used due to its availability and similarity to the F/A-18. Sommers (1989, pp. 12-14) discusses some differences between the YF-17 and F/A-18. Figure 2 and Figure 3 show three-view drawings of the F/A-18 and YF-17, respectively, and depict some of these differences. The model was sting-mounted in the vertical plane in the test section (see figure 8 of chapter III, section B). For more details on model mounting, see Sommers (1989, p. 16).

Both sets of leading edge extension (LEX) slots on the YF-17 model were filled with putty to more closely resemble the F/A-18. Some of the key dimensions of the model are:

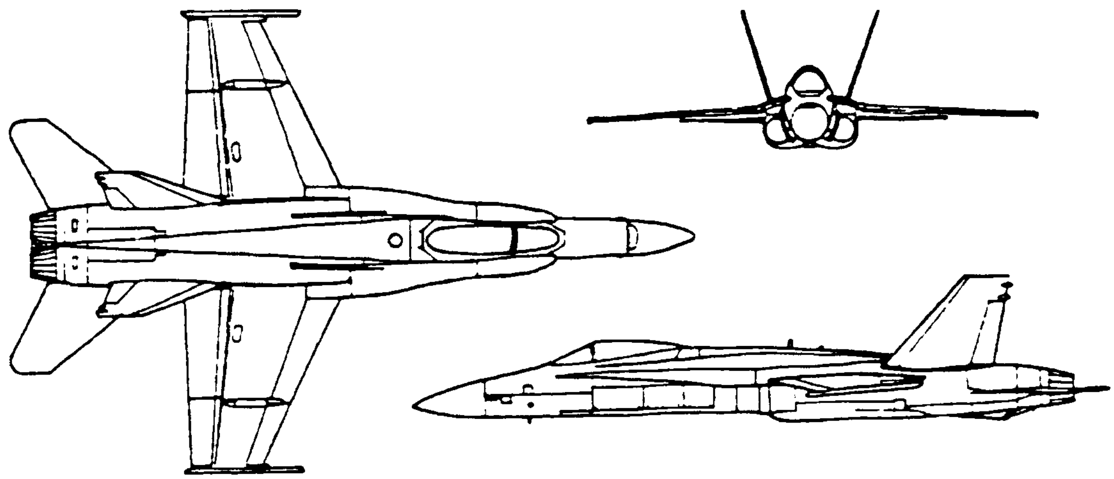

Figure 2. McDonnell Douglas F/A-18

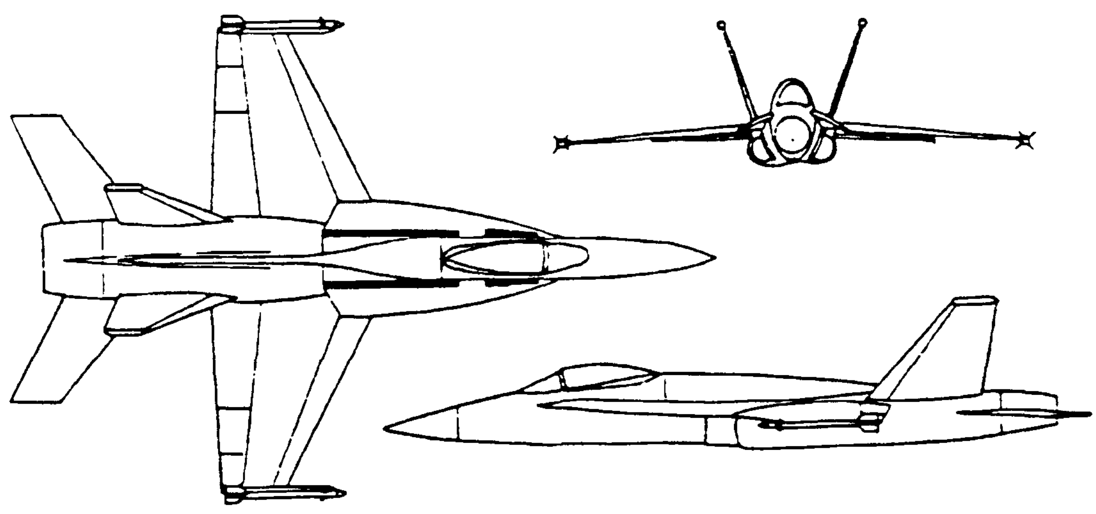

Figure 3. Northrop YF-17 (3% Scale Model)

1. Overall length: 19.12 inches.

2. Wing span: 12.60 inches.

3. Wing area: 45.36 inches.

C. SMOKE GENERATOR

A Rosco model 1500 smoke generator system is installed in the NPS wind tunnel for flow visualization. It is suitable for flow visualization with or without laser sheet. Only smoke was employed during the present investigation. A Canon T70 camera with flash unit, and a Nikon 2000 camera without flash were used to record vortex patterns shed off the LEXs. More details pertaining to the smoke generator and flow visualization may be found in Sommers (1989, pp. 23-25).

D. HOT-WIRE

DISA hot-wire equipment was used for cross probe hot-wire measurements. A DISA cross-probe model 55P51 was used in conjunction with a pair of CTA model 56C17 bridges, and pairs of model 56N21 linearizers and model 56N20 signal conditioners. An analog processing unit, model 56N23 combined the instantaneous outputs A and B from the two bridges to give A + B, and A - B. These signals were fed into both a model 56N25 root mean square (RMS) unit, and a model 56N22 mean value unit. A model 56B10 main frame housed these components as depicted in Figure 4.

The cross hot-wire probe consists of two hot-wires perpendicular to each other, as viewed from the side, and also at a 45 degree angle to the horizontal as installed in the wind tunnel. Figure 5 shows this arrangement. The linearized output voltages of A and B are proportional to U + V, and to U - V respectively (Hebbar, 1981, p. 25).

Where: U = instantaneous velocity in axial direction.

V = instantaneous velocity in lateral direction.

$\bar{U}$ = mean flow velocity in axial direction.

$\bar{V}$ = mean flow velocity in lateral direction.

u = velocity fluctuation in axial direction.

v = velocity fluctuation in lateral direction.

$\langle u \rangle$ = RMS of u.

$\langle v \rangle$ = RMS of v.

$A = k(U + V)$.

$B = k(U - V)$.

k = sensitivity constant for each wire.

It can be shown that:

$$\bar{U} = (1/2k) \times (\overline{A + B}).$$

$$\bar{V} = (1/2k) \times (\overline{A - B}).$$

$$\langle u \rangle = (1/2k) \times \langle A + B \rangle.$$

$$\langle v \rangle = (1/2k) \times \langle A - B \rangle.$$

CTA A	Lin A	SC A	APU	SC B	Lin B	CTA B	RMS Unit	Mean Value Unit
56C17	56N21	56N20	56N23	56N20	56N21	56C17	56N25	56N22

Figure 4. DISA Hot-Wire Equipment Set-Up

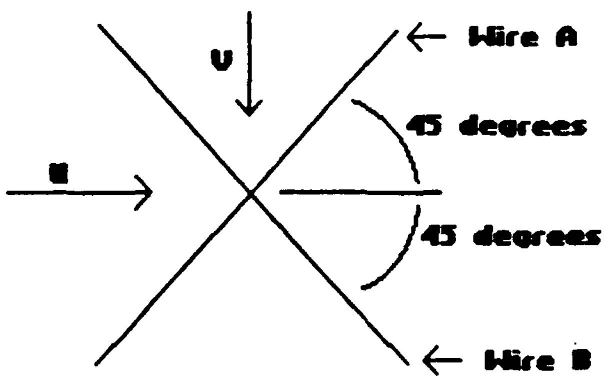

Figure 5. Cross Hot-Wire Probe

The hot-wire probe was mounted on a traversing mechanism [Fig. 6]. This allowed surveying laterally by turning the traversing crank. Vertical positioning was accomplished by adjusting the traversing mechanism head.

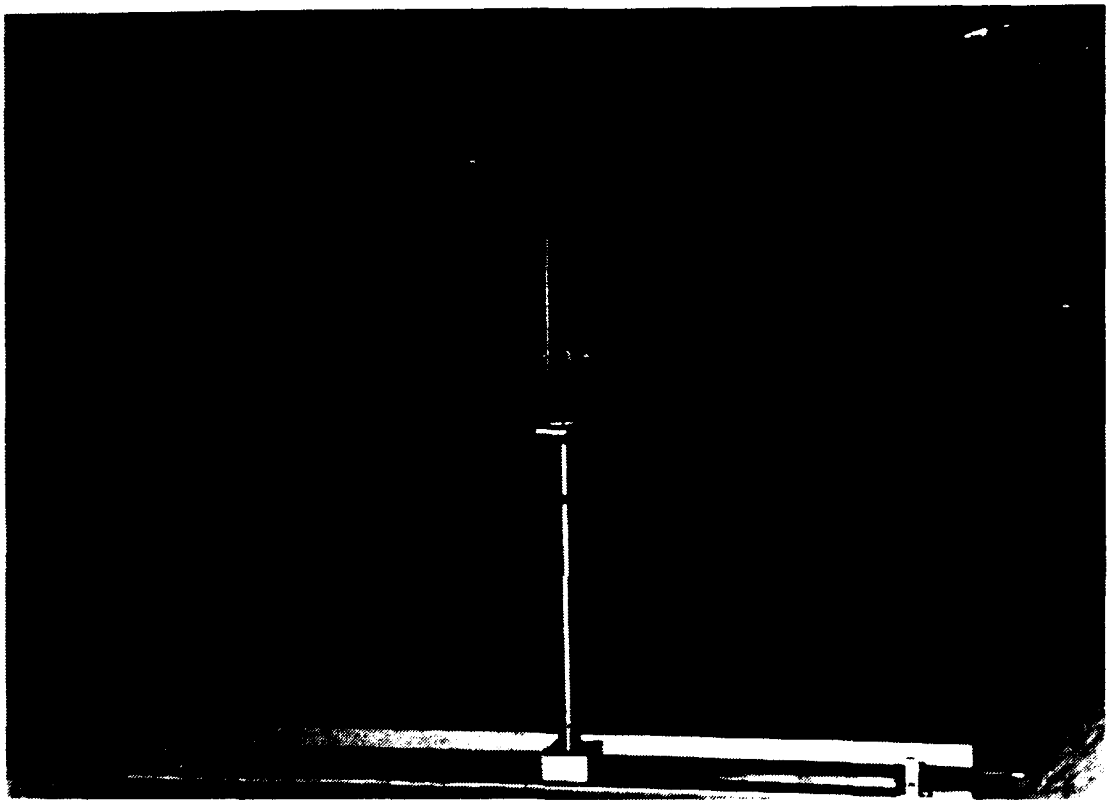

Figure 6. Traversing Mechanism

E. SPECTRUM ANALYZER

A GenRad model GR2512 spectrum analyzer was used to analyze the spetral response of the hot-wires. This information was used to determine power spectral density (PSD) of fluctuations. Spectra were recorded using a Tektronix model 4632 video hard copy unit.

III. EXPERIMENTAL PROCEDURE

A. GENERAL

Smoke flow visualization was used to locate the vortex wake downstream of the model. Cross hot-wire measurements were taken at three downstream survey locations: 1) station E-16, seven feet downstream from the center of the test section, and 16 inches above the tunnel floor, as illustrated in Figure 7. This station is approximately three model lengths aft of the model, and represents the 235-foot downstream location of the vane structures in the NASA Ames 80- by 120-foot wind tunnel; 2) station E-12, same as E-16 but 12 inches above the tunnel floor; 3) station B, a near downstream location three inches aft of the model support column, at a height two inches above the model centerline, as illustrated in Figure 8.

B. HOT-WIRE SURVEYS

1. Hot-wire measurements at E stations

At a test section velocity of 50 meters/second, horizontal hot-wire surveys were made at stations E-16 and E-12, with the model set at angles of attack (AOA) 0, 10, 20, 25, 30, 40, and 50 degrees. The LEX fence was off during these surveys.

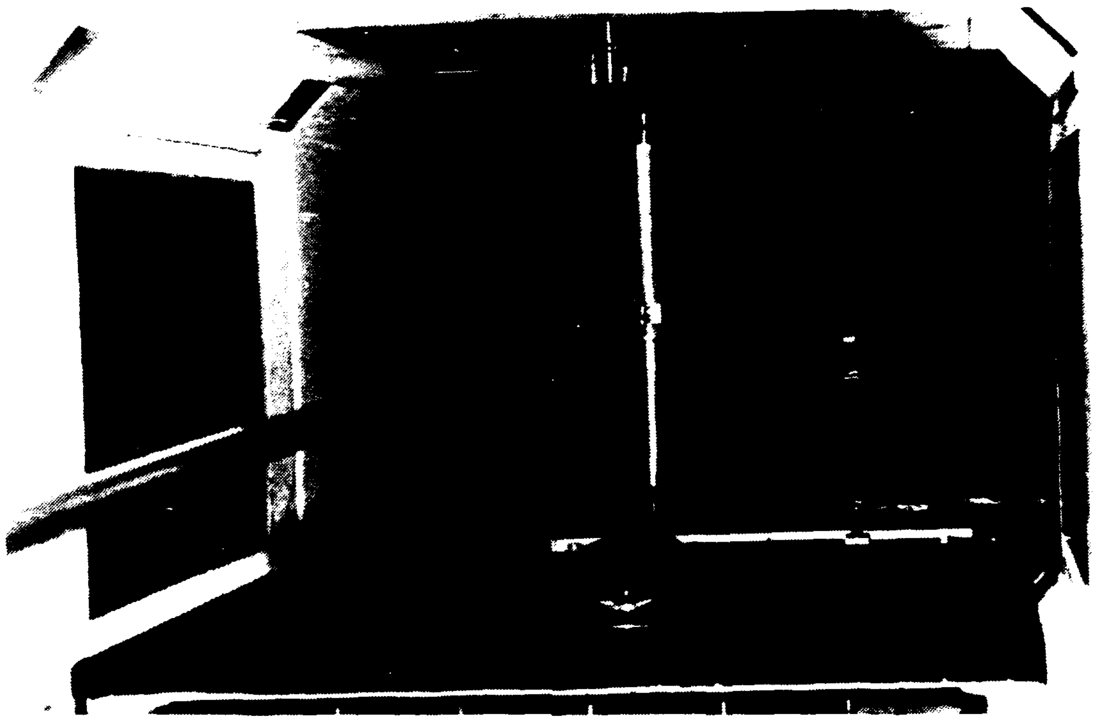

Figure 7. Set-Up for Hot-Wire Surveys at Station E

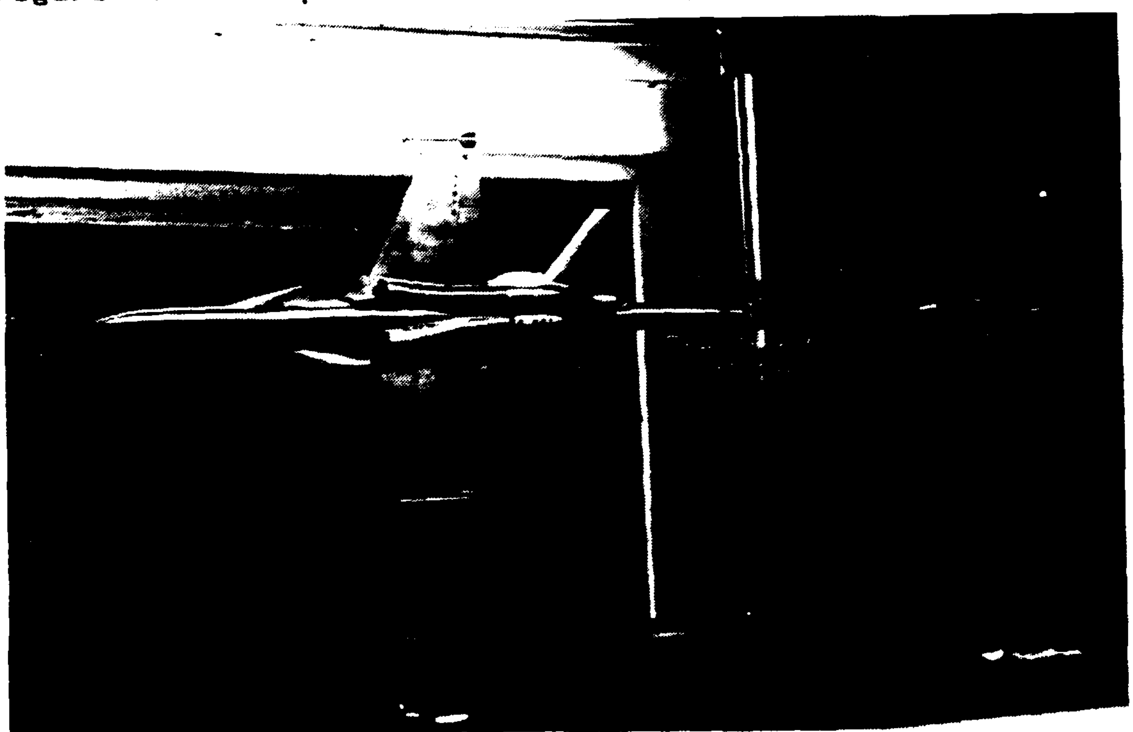

Figure 8. Set-Up for Hot-Wire Surveys at Station B

2. Hot-wire measurements at station B

At a velocity of 50 meters/second, horizontal hot-wire surveys were made at station B with the model set at angles of attack of 20, 22, 24, 26, 28, and 30 degrees in order to find the angle of attack yielding the greatest fluctuation. Additional surveys were made at angles of attack of 23 and 25 degrees. The LEX fence was off during these surveys.

3. Hot-wire measurements at station B with AOA yielding greatest fluctuation and LEX fence off

Without the LEX fence, and with the model at the angle of attack that yielded the greatest fluctuation, as determined in the preceding step, horizontal hot-wire surveys were made at test section velocities of 10, 20, 30, 40, and 50 meters/second. Representative power spectra were taken from the output of hot-wire A.

4. Hot-wire measurements at station B with AOA yielding greatest fluctuation and LEX fence on

A three-percent scaled version of the NASA Ames CFD simplified LEX fence [Fig. 9] was installed on the model. The two fences used in this investigation were constructed from 1/32-inch balsa wood and installed, one on each side of the YF-17 model near the junction of the LEX and the wing [Fig. 10]. The hot-wire and spectra measurements were then repeated for flow conditions and model orientation as specified in 3.

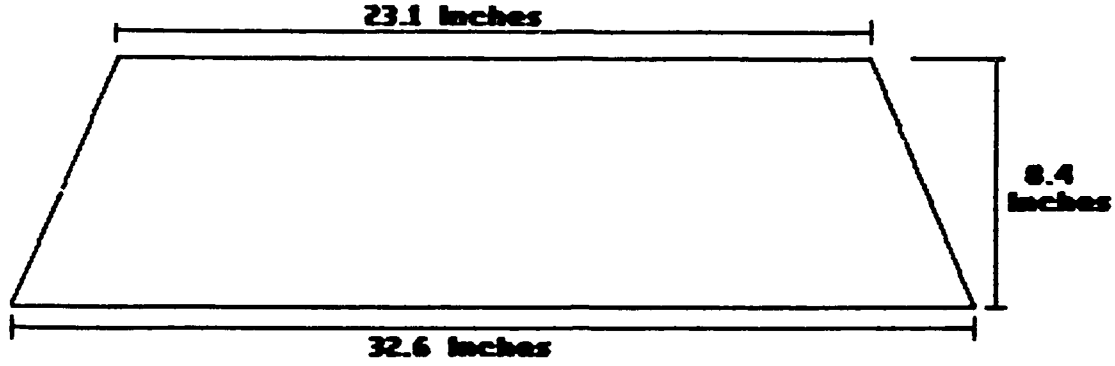

Figure 9. NASA Ames CFD Simplied LEX Fence

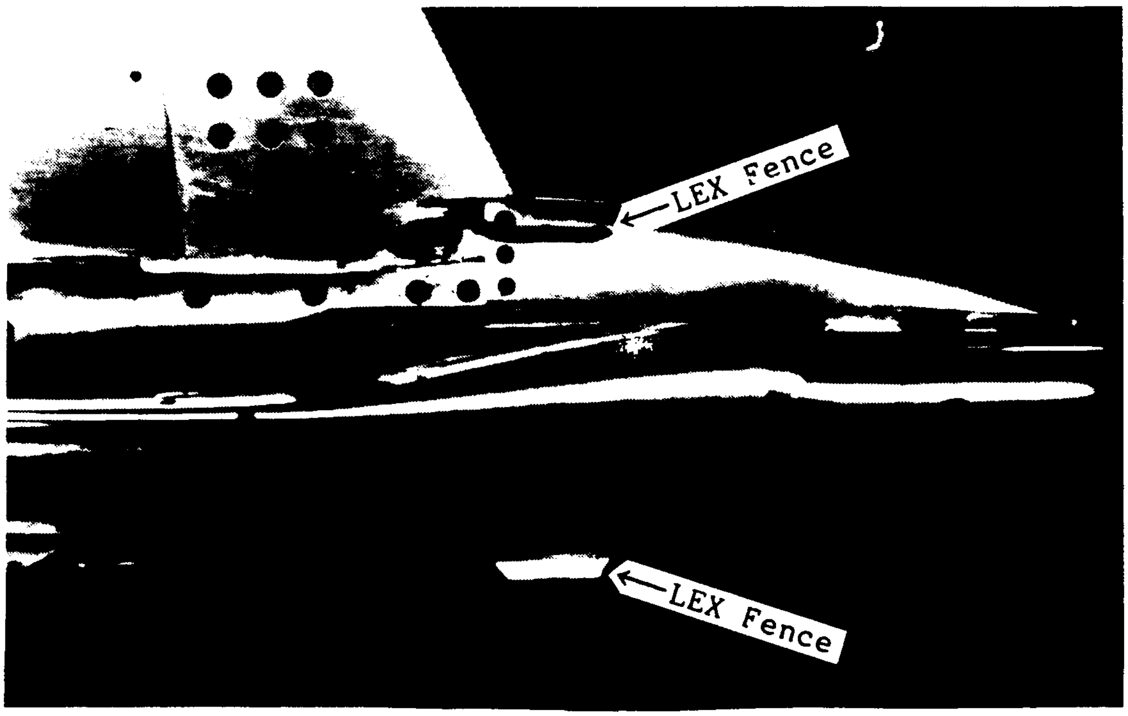

Figure 10. LEX Fence on YF-17 Model

IV. RESULTS AND DISCUSSION

A. FLOW VISUALIZATION

Flow visualization by injection of smoke into the wind tunnel test section at low speeds (5 - 10 m/s) helped determine approximate location of vortices. These locations were used to determine where to make hot-wire surveys. Figure 11 and Figure 12 show vortex formations for AOAs 20 and 50 degrees respectively.

B. HOT-WIRE MEASUREMENT

1. At far downstream stations

Hot-wire data obtained for the far downstream station consisted of mean value of A+B, which is proportional to mean velocity component $\bar{U}$. These data were obtained for a horizontal sweep at stations E- and E-12. Each set of data was normalized against the local maximum mean velocity, yielding a non-dimensional value. These data are presented graphically for AOAs of 0, 10, 20, 25, 30, 40, 50, and 60 degrees in Figures 13-28, in the Appendix. The numbers on the horizontal axis represent distance in inches read off the scale on the traverse, 15 corresponding to the centerline of the tunnel.

Figure 11. Vortex Formation at 20 Degrees AOA

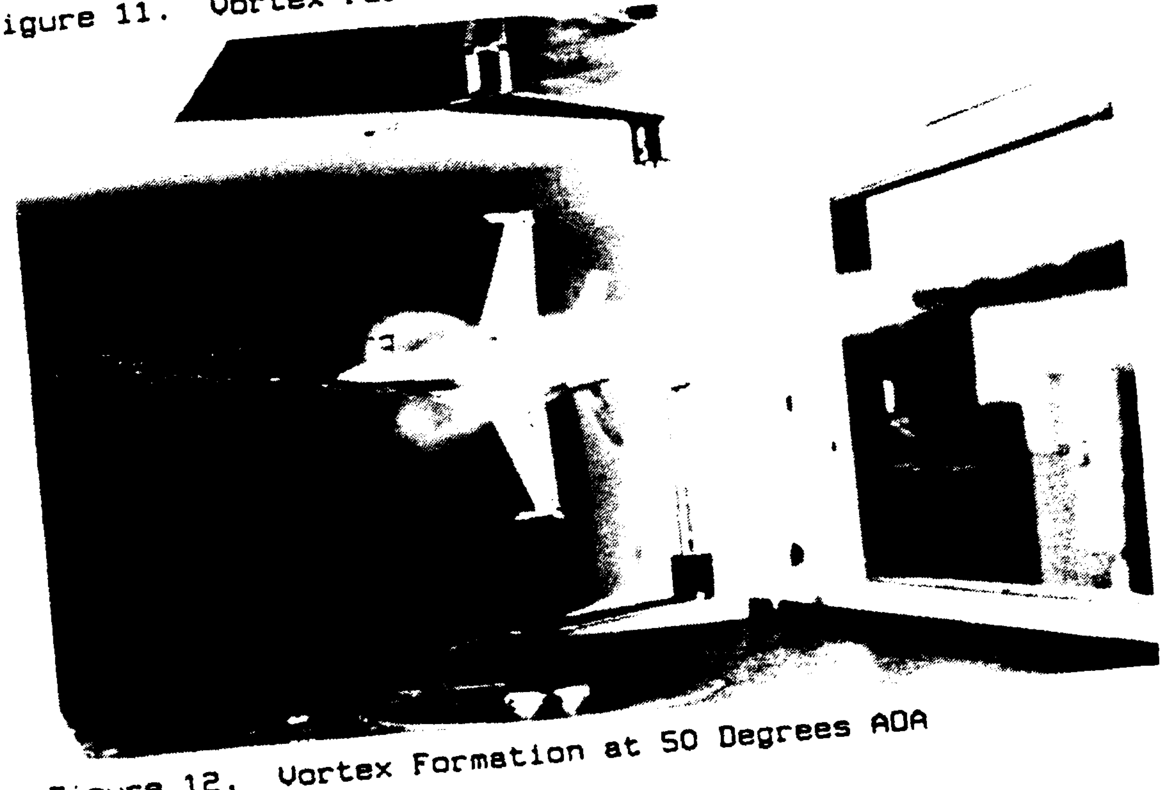

Figure 12. Vortex Formation at 50 Degrees AOA

The data points are shown connected by straight line for better visibility. Uncertainty of the measurements was +/- 0.002. The graphs are scaled for maximum clarity, therefore the deviations may at first appear to be greater than they really are. Attention to the scaling of each graph is therefore warranted.

The variation of the mean velocity across the wake tended to spread out as AOA was increased. The maximum deviation occurred between AOAs of 25 and 40 degrees.

RMS values, which were desired as a measure of turbulence, were not recorded as they consistently read extremely low values close to zero. The RMS unit available read only to the nearest one-hundredth of a volt and was not sensitive enough to detect any very small RMS voltages that may have been present. However, the absence of measurable RMS values supports the later conclusion that turbulence had greatly diminished at the far downstream station.

2. Finding AOA yielding greatest fluctuation

Hot-wire data obtained at the near downstream station (station B) consisted of mean value of A+B, being proportional to mean velocity component $\overline{U}$, and RMS value of A-B, which is proportional to <v>, the lateral component of turbulence.

Initially, these data were obtained at AOAs of 20, 22, 24, 26, 28, and 30 degrees. Since AOA of 24 degrees appeared to yield the greatest fluctuation, additional data were obtained at AOAs of 23 and 25 degrees to better determine the correct AOA.

These RMS values (<v>) were normalized against the mean values ($\bar{U}$) for each data point. These data are presented graphically in Figures 29-36, in the Appendix. Peaks that are due to the model support column are marked "Support Column Wake" and should be disregarded here. Figures 37-44 show mean velocity distribution obtained from these hot-wire surveys at station B.

As the AOA was increased up to and including 25 degrees, the peak turbulence increased. After 25 degrees AOA, the turbulence peak dropped and expanded laterally. This parallels results found by Cavazos (1990, pp. 24-27) in his water tunnel studies of LEX vortices of an F/A-18 model at high angles of attack. The results showed there was a vortex core originating at the LEX that tended to burst earlier for AOAs greater than 25 degrees.

3. Effects of LEX fence

At the near downstream station, hot-wire data were obtained for cases of no LEX fence and LEX fence installed. These data, as in the case of finding the AOA of greatest fluctuation, consisted of mean values of A+B, proportional to $\bar{U}$, and RMS values of A-B, proportional to <v>.

These data were gathered at the greatest fluctuation AOA (25 degrees), for test section velocities of 10, 20, 30, 40, and 50 meters per second.

RMS values of A-B were normalized against mean values of A+B at each data point. These non-dimensional data are presented in Figures 45-54, in the Appendix. Again, the peaks caused by the support column should be disregarded.

It can be seen that wind speed had no measurable effect on turbulence intensity. That is, turbulence appears to vary in direct proportion to mean velocity, yielding a uniform normalized turbulence distribution along the surveys.

Any differences in turbulence intensity between the case of no LEX fence [Fig. 45-49] and LEX fence installed [Fig. 50-54] are not discernable. Considering the error band, no conclusion can be made either way about whether or not the LEX fence affected the overall turbulence intensity.

C. POWER SPECTRA

Spectra were obtained for cases of no LEX fence and LEX fence installed, at wind velocities of 10, 20, 30, 40, and 50 meters per second. The spectra were recorded for each case that was shown in Figures 45-54 at the maximum turbulence values (disregarding the support column peaks).

Spectra are presented in the Appendix for no LEX fence [Fig. 55-59] and for LEX fence installed [Fig. 60-64]. Energy content is shifted to the right, toward higher frequencies for the case of LEX fence installed. This redistribution of turbulence to higher frequencies is a desired effect of adding the LEX fence, and if done properly could move turbulence away from the critical low frequencies of the vertical tail.

V CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

At the request of NASA Ames Research Center, a low-speed wind tunnel investigation was conducted to examine the vortex wake downstream of a three-percent scale model of the YF-17 lightweight fighter prototype at high angles of attack. The investigation demonstrated that the lateral turbulent fluctuation in the wake approximately 3 model lengths downstream had diminished considerably. It was found that peak turbulent fluctuation at a near downstream station, just aft of the model, occurred with the model at approximately 25 degrees angle of attack. This observation was made at 10, 20, 30, 40, and 50 meters/second velocities, and leads to the conclusion that, within the tested range, the peak turbulence intensity was independent of the mean velocity. Finally, it was observed that the addition of a fence to the leading edge extenstion (LEX) shifted the power spectrum toward higher frequencies.

B. RECOMMENDATIONS

Additional hot-wire measurements should be made at station B, but using a vertical survey as opposed to a horizontal survey. This would enable the probe to be placed directly aft of the vertical tail, because the support column would not interfere as the survey would be parallel to the column. Two advantages would be reaped: 1) closer proximity to the model, and hence vortex burst locations; and 2) no support column induced turbulence showing up in the data. These surveys should yield well defined data that could be correlated with results found here.

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APPENDIX

FIGURES 13 THROUGH 64

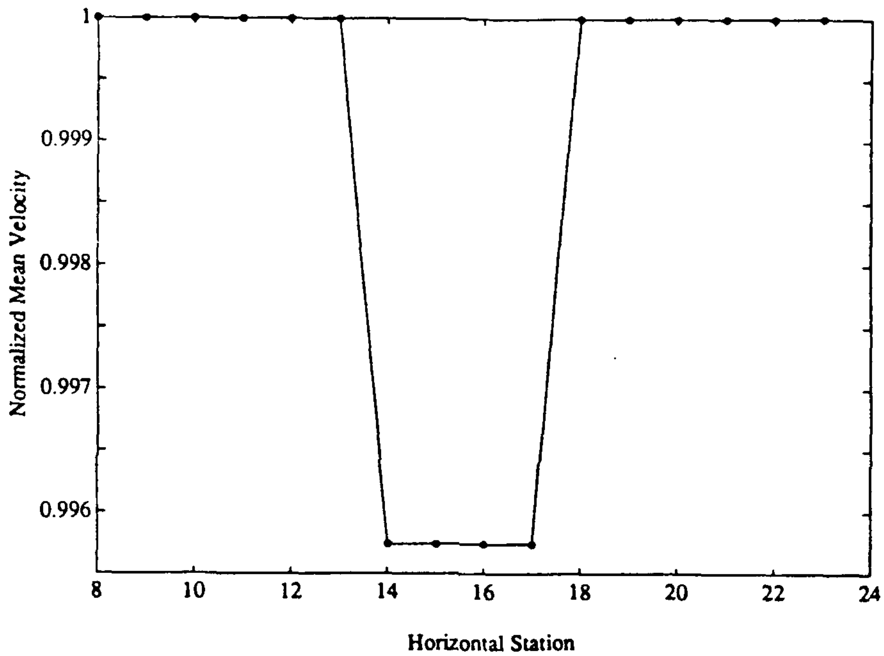

Figure 13. Station E-16, Velocity = 50 m/s, AoA = 0 degrees

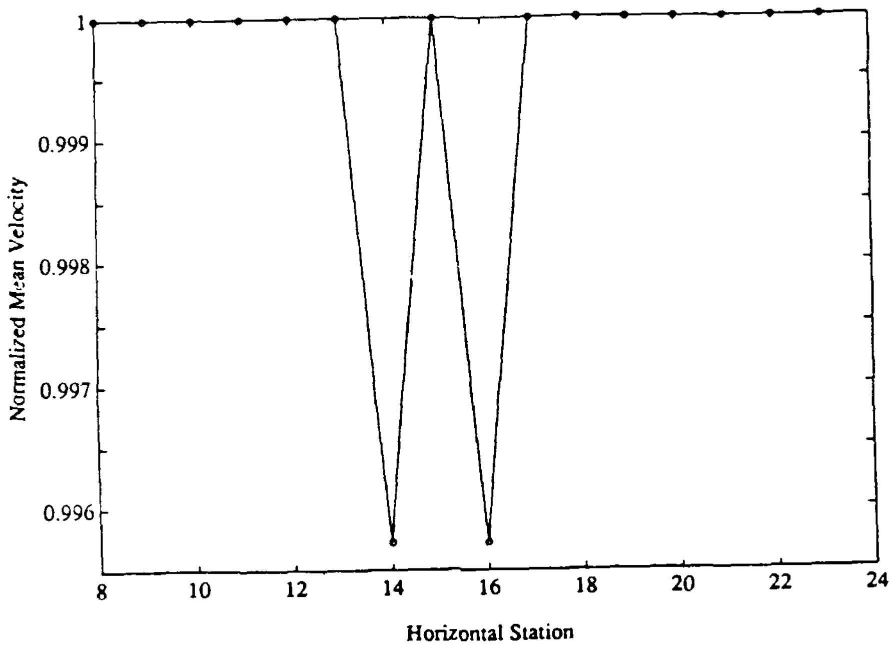

Figure 14. Station E-16, Velocity = 50 m/s, AoA = 10 degrees

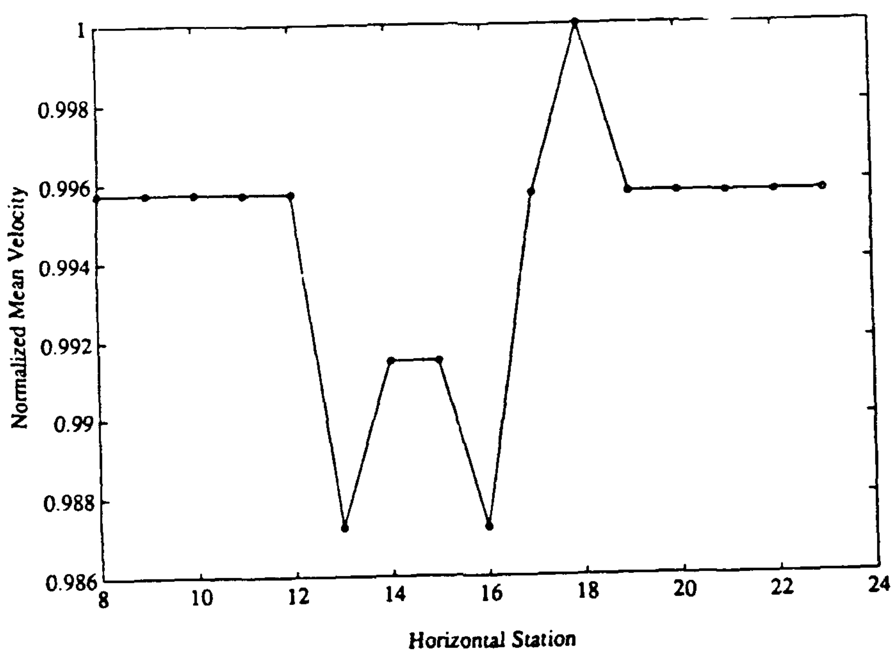

Figure 15. Station E-16, Velocity = 50 m/s, AoA = 20 degrees

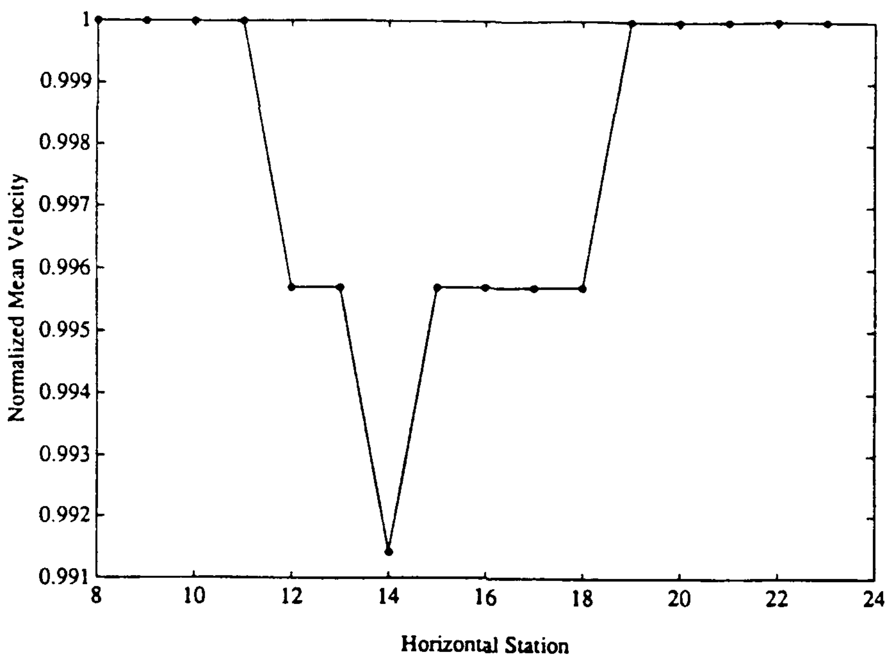

Figure 16. Station E-16, Velocity = 50 m/s, AoA = 25 degrees

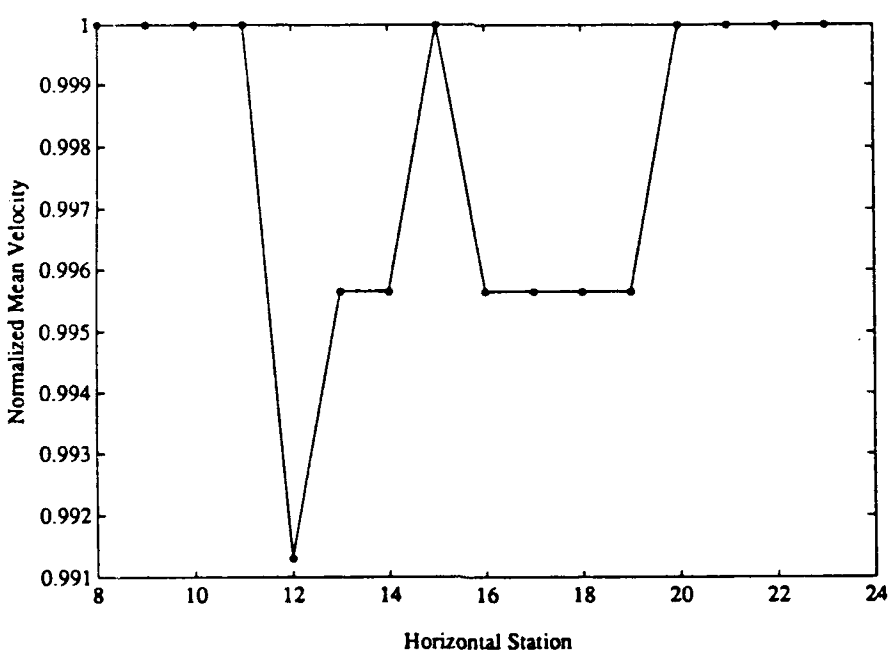

Figure 17. Station E-16, Velocity = 50 m/s, AoA = 30 degrees

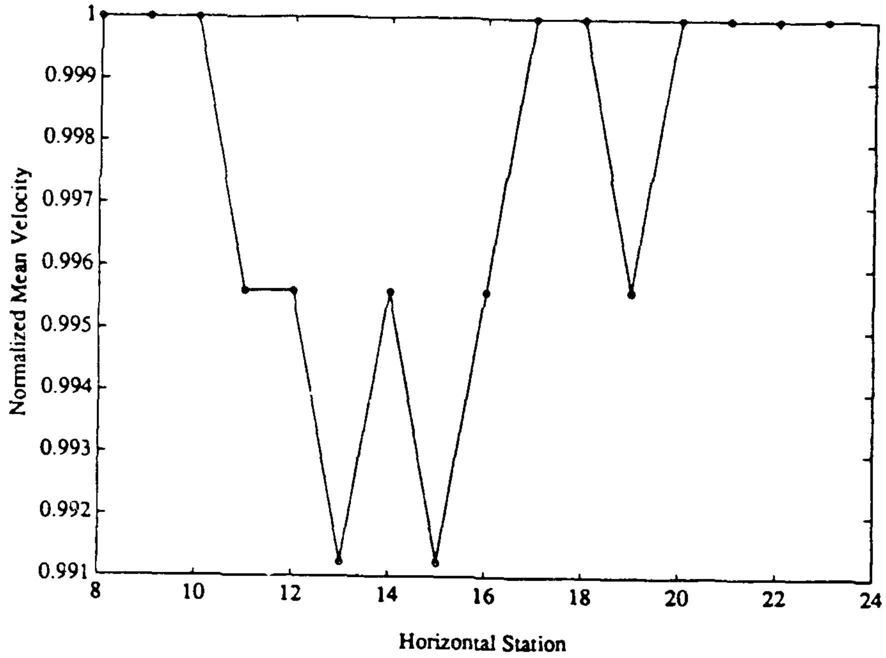

Figure 18. Station E-16, Velocity = 50 m/s, AoA = 40 degrees

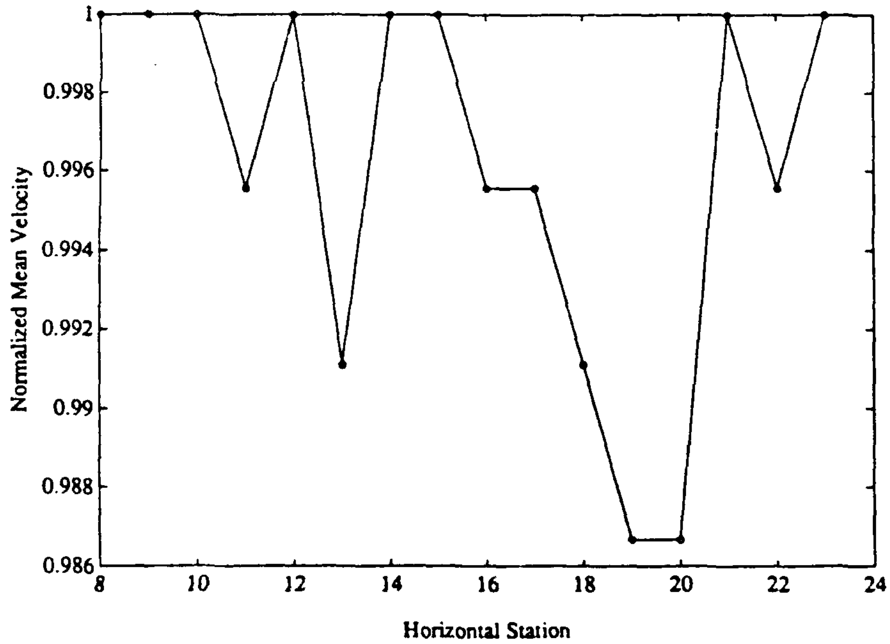

Figure 19. Station E-16, Velocity = 50 m/s, AoA = 50 degrees

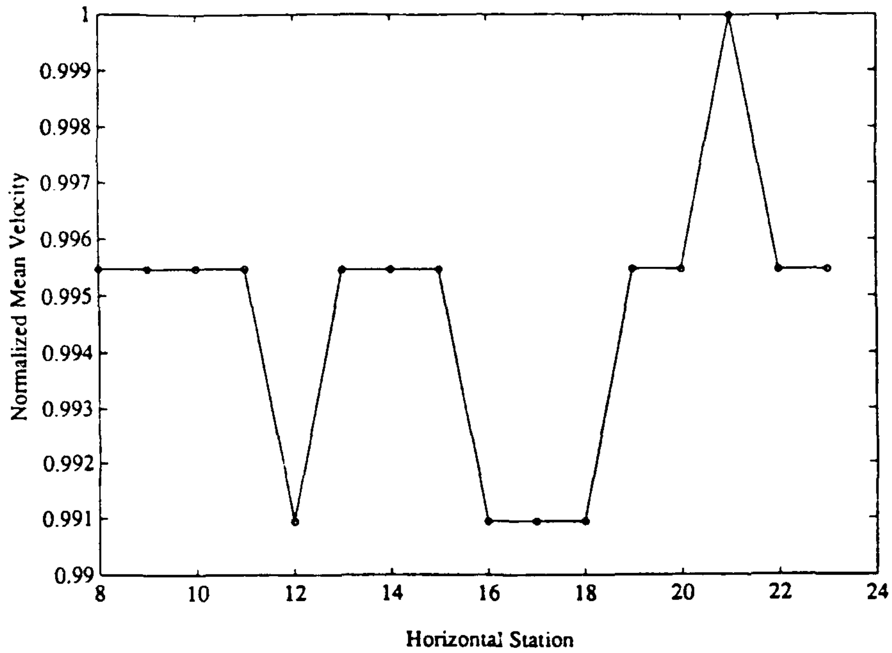

Figure 20. Station E-16, Velocity = 50 m/s, AoA = 60 degrees

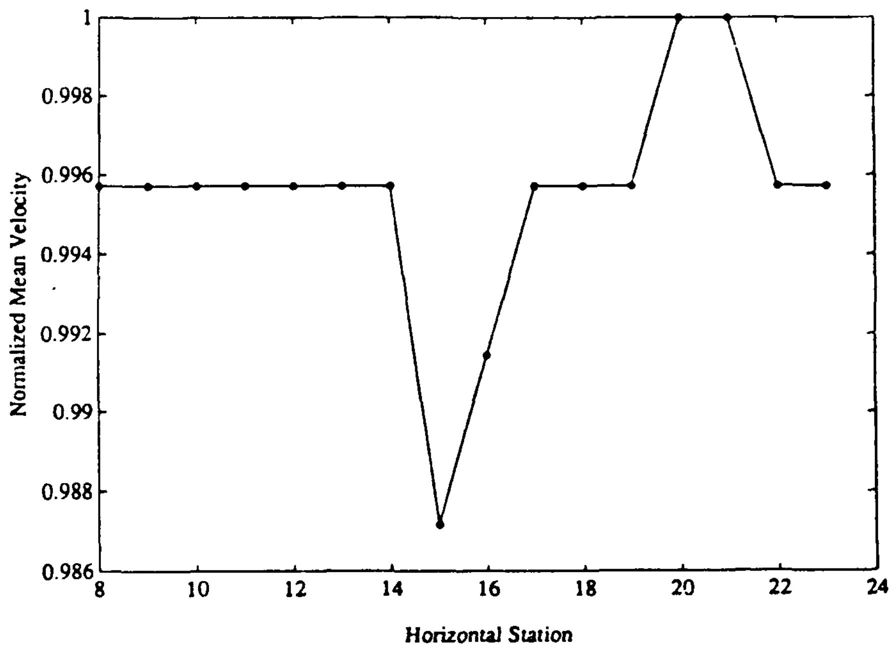

Figure 21. Station E-12, Velocity = 50 m/s, AoA = 0 degrees

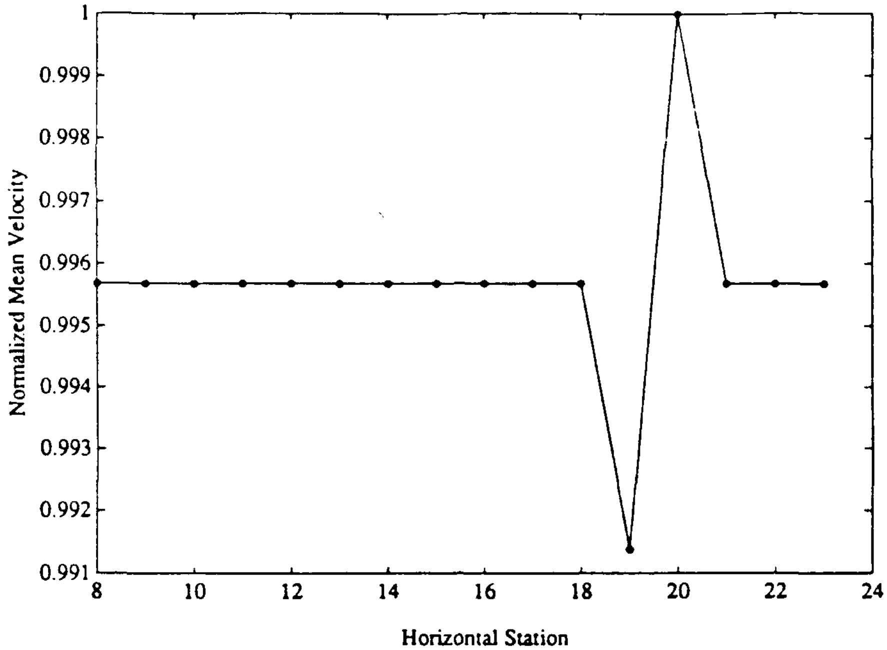

Figure 22. Station E-12, Velocity = 50 m/s, AoA = 10 degrees

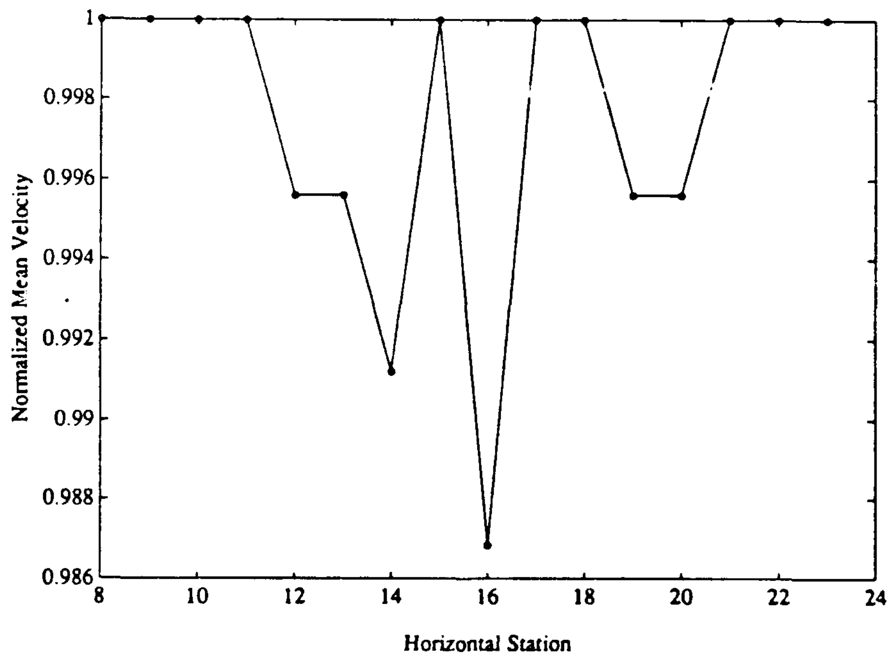

Figure 23. Station E-12, Velocity = 50 m/s, AoA = 20 degrees

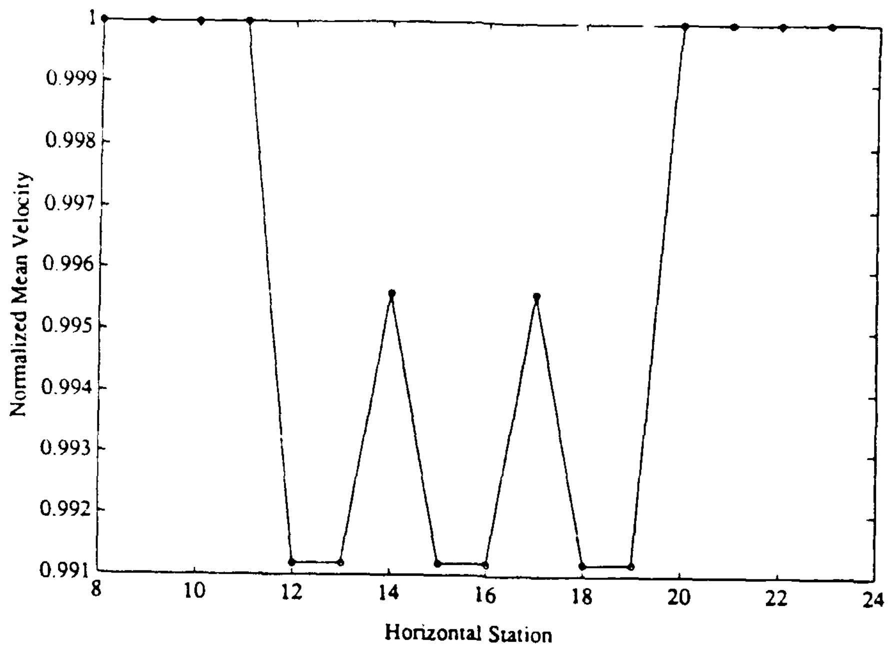

Figure 24. Station E-12, Velocity = 50 m/s, AoA = 25 degrees

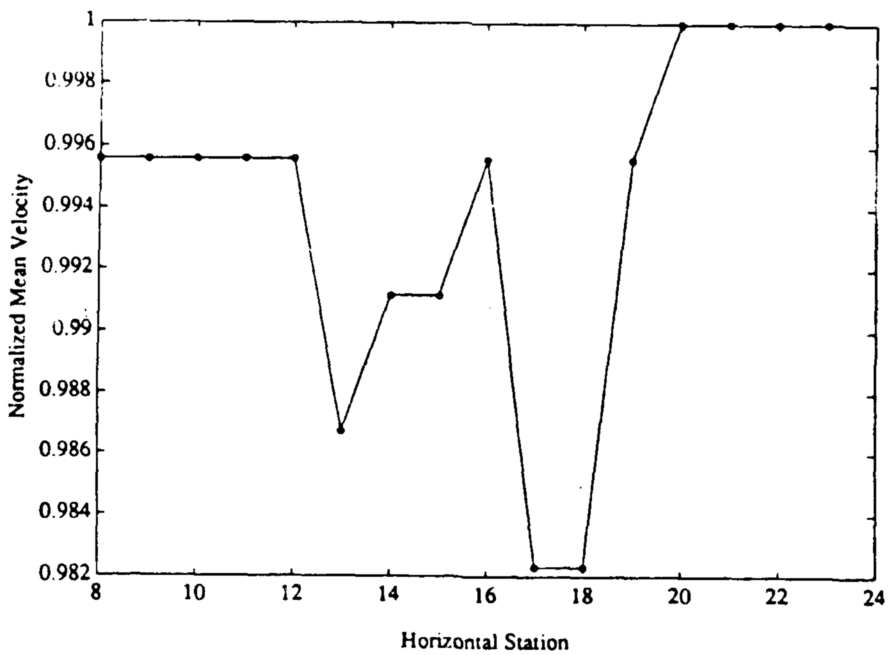

Figure 25. Station E-12, Velocity = 50 m/s, AoA = 30 degrees

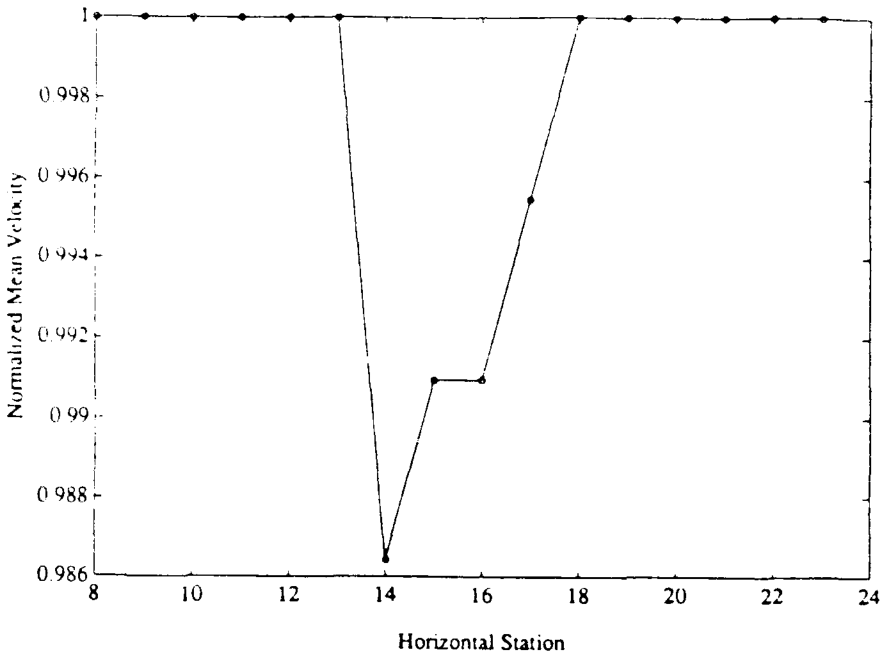

Figure 26. Station E-12, Velocity = 50 m/s, AoA = 40 degrees

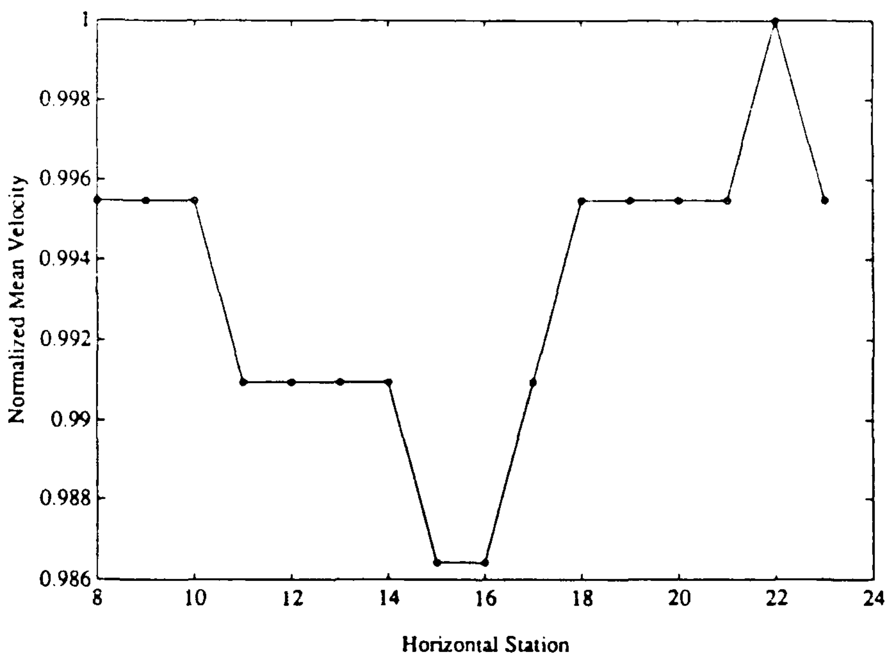

Figure 27. Station E-12, Velocity = 50 m/s, AoA = 50 degrees

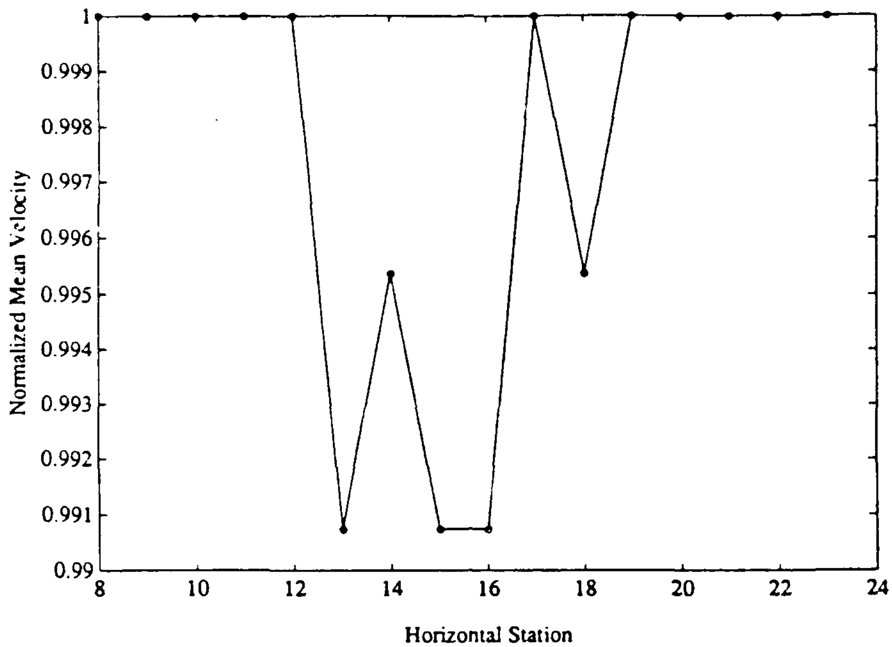

Figure 28. Station E-12, Velocity = 50 m/s, AoA = 60 degrees

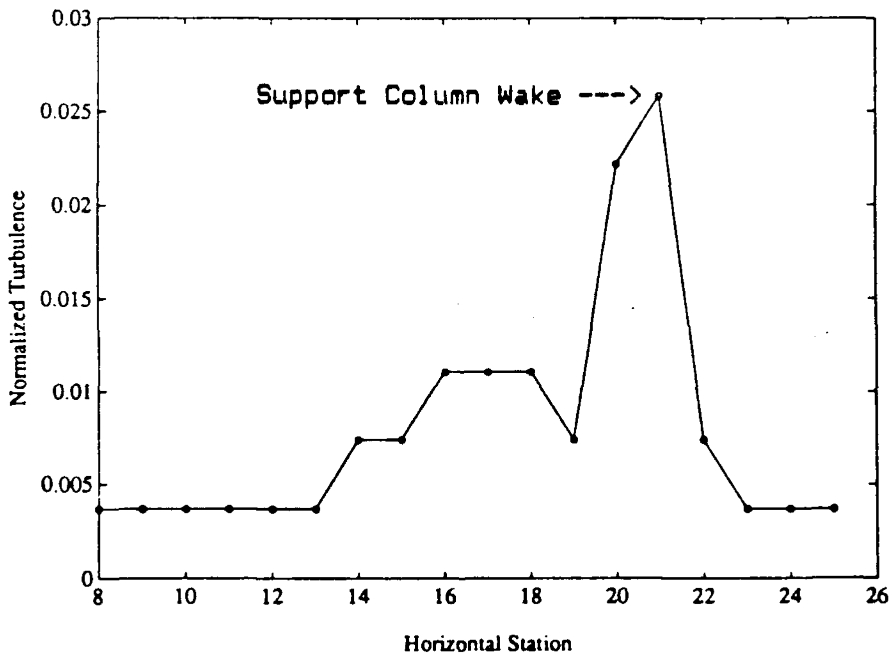

Figure 29. Station B, Velocity = 50 m/s, AoA = 20 degrees

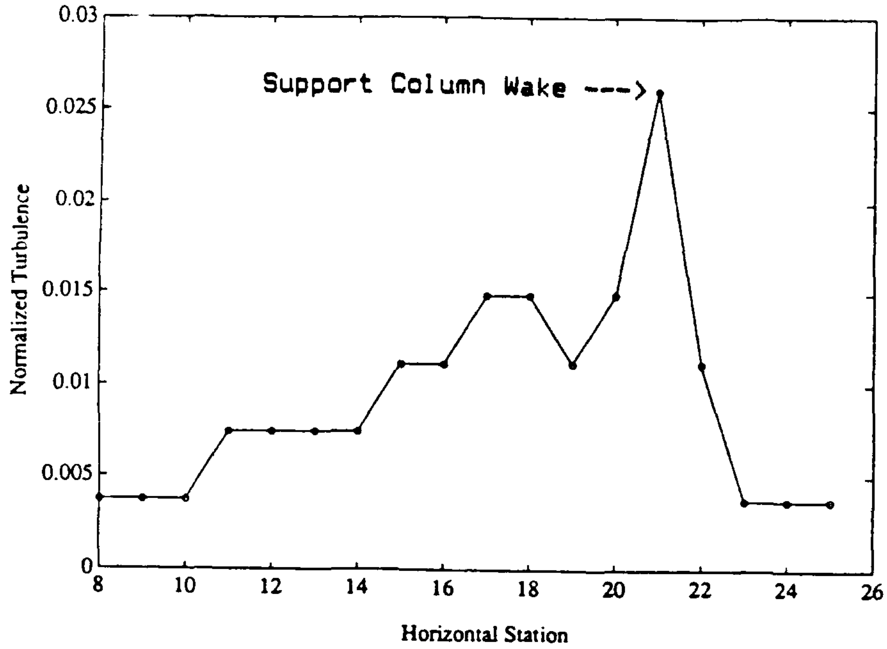

Figure 30. Station B, Velocity = 50 m/s, AoA = 22 degrees

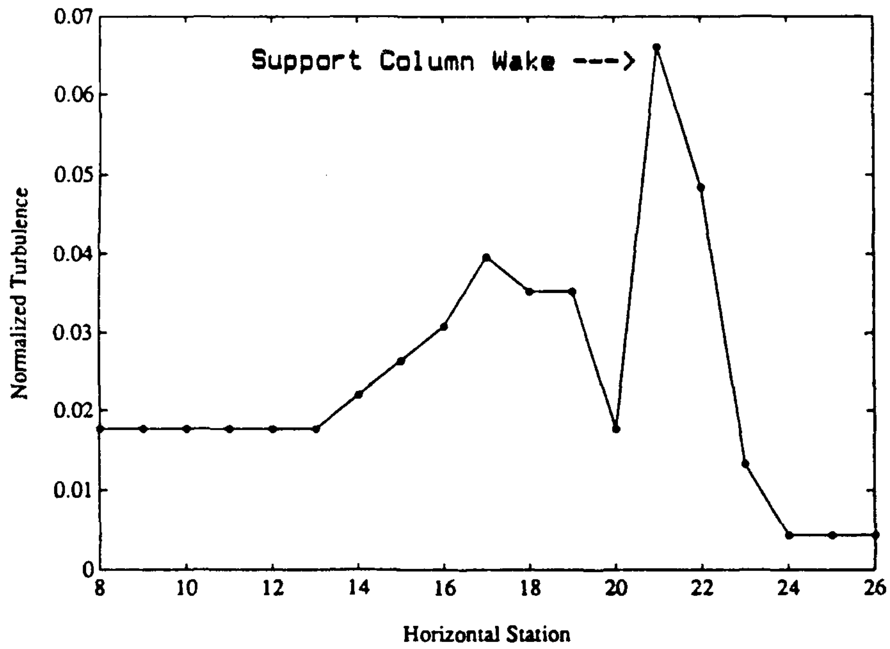

Figure 31. Station B, Velocity = 50 m/s, AoA = 23 degrees

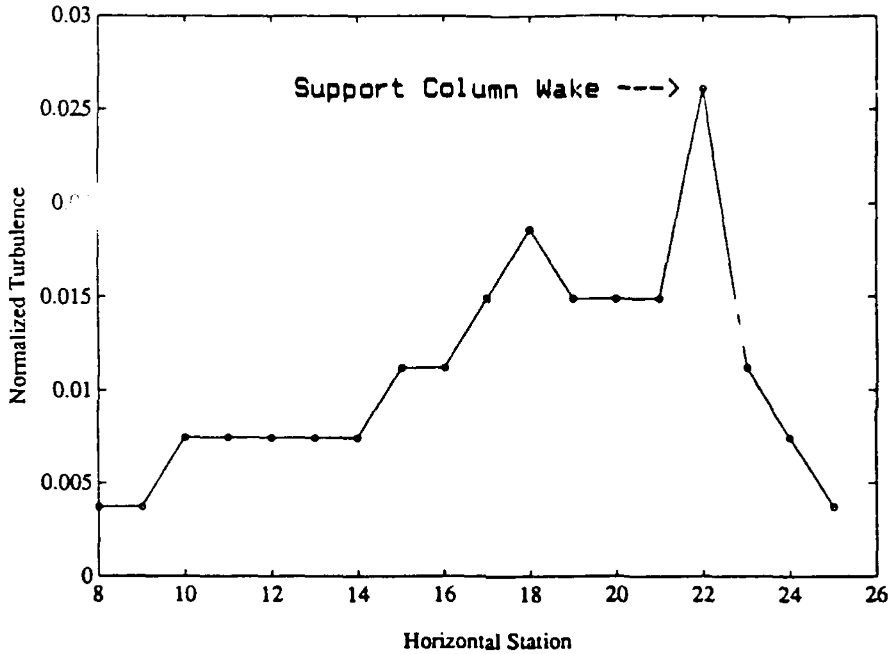

Figure 32. Station B, Velocity = 50 m/s, AoA = 24 degrees

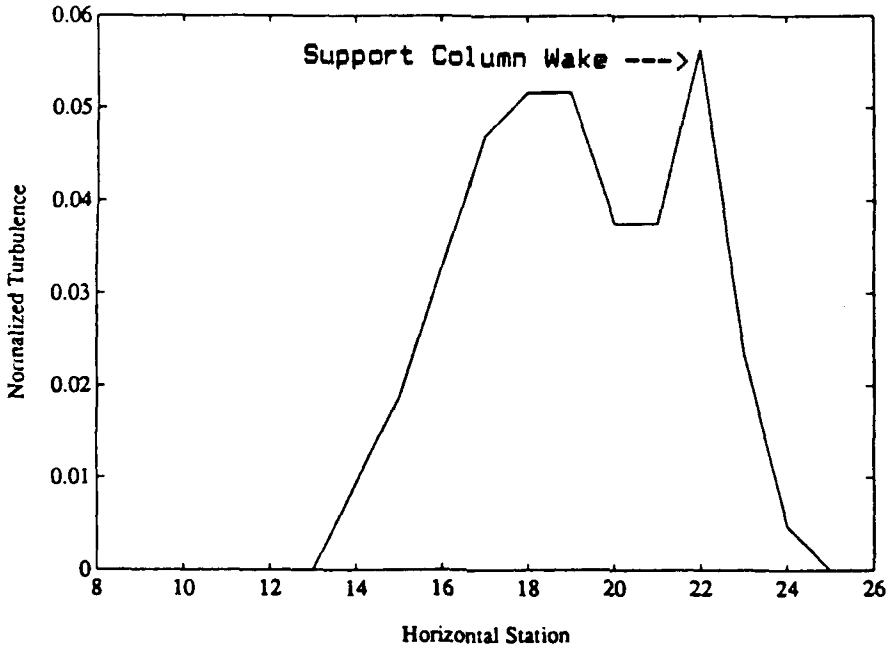

Figure 33. Station B, Velocity = 50 m/s, AoA = 25 degrees

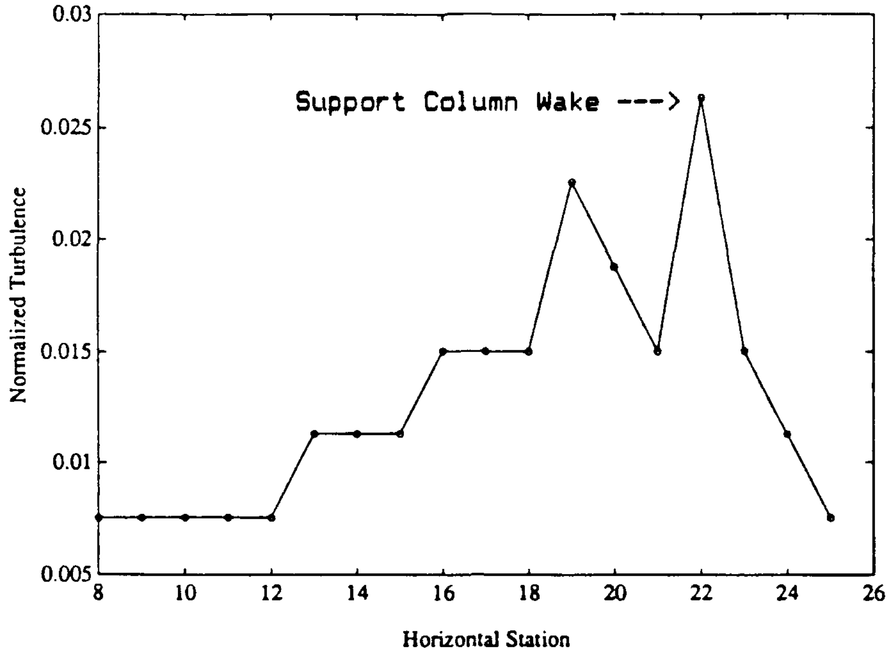

Figure 34. Station B, Velocity = 50 m/s, AoA = 26 degrees

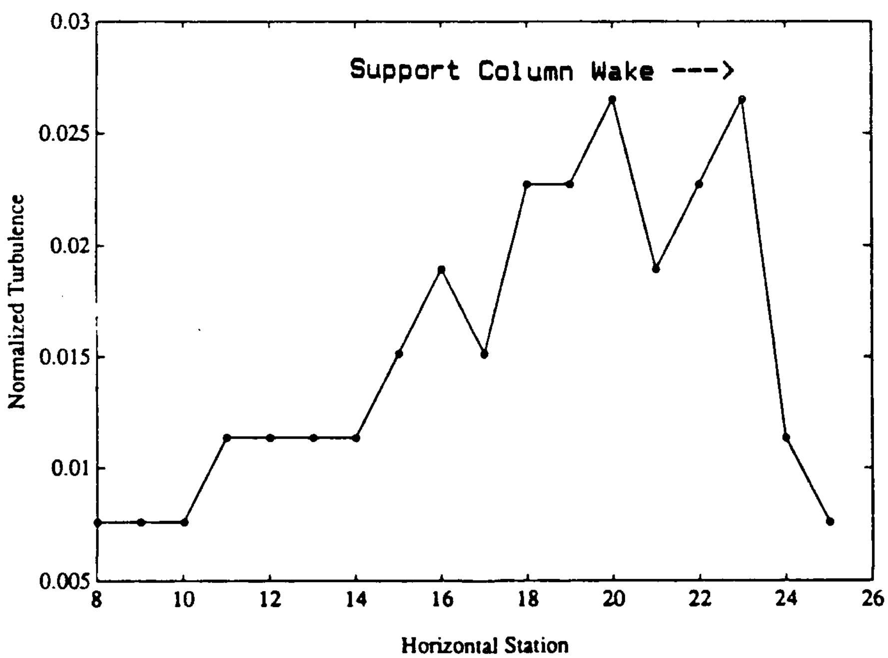

Figure 35. Station B, Velocity = 50 m/s, AoA = 28 degrees

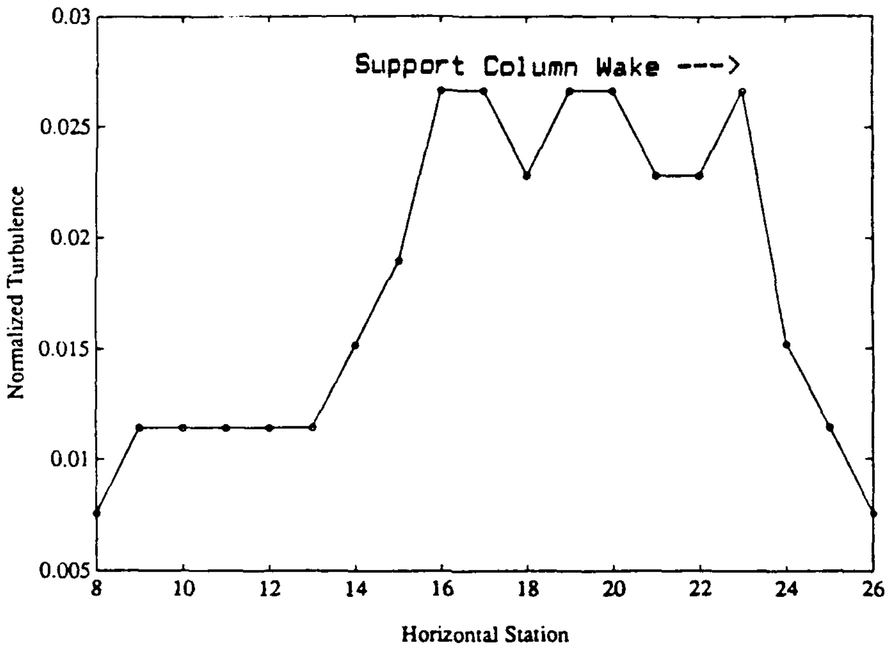

Figure 36. Station B, Velocity = 50 m/s, AoA = 30 degrees

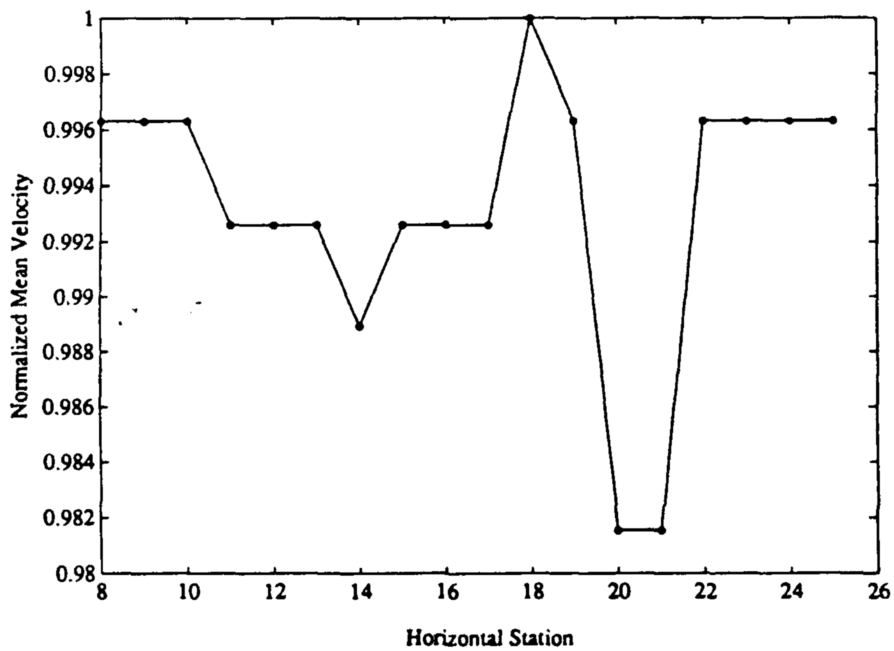

Figure 37. Station B, Velocity = 50 m/s, AoA = 20 degrees

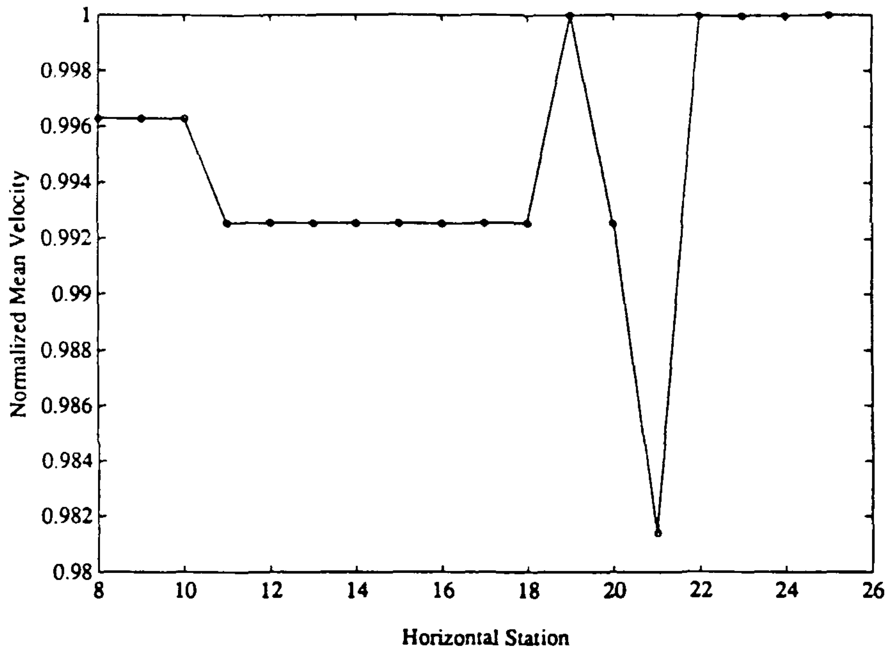

Figure 38. Station B, Velocity = 50 m/s, AoA = 22 degrees

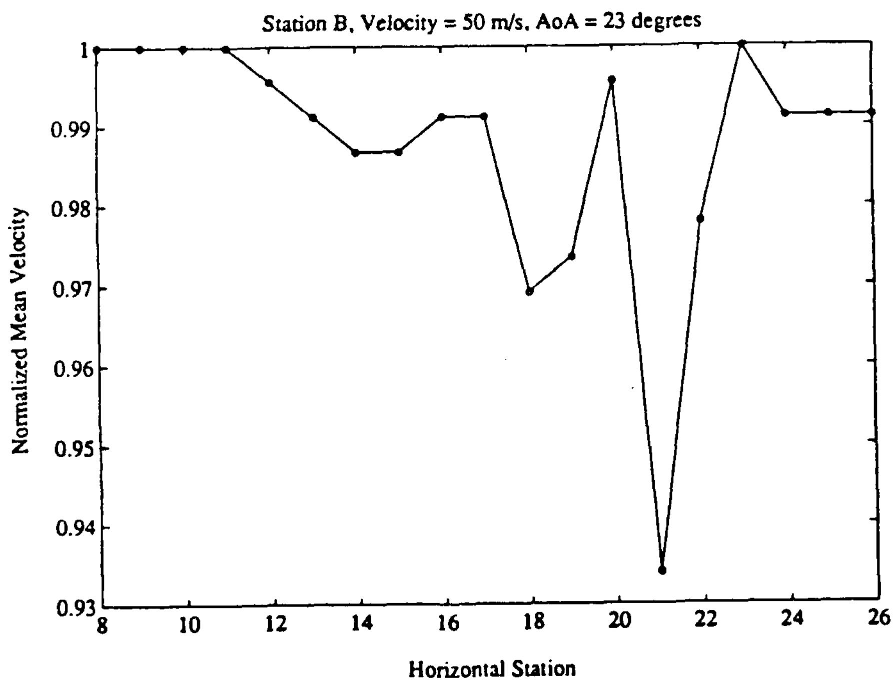

Figure 39. Station B, Velocity = 50 m/s, AoA = 23 degrees

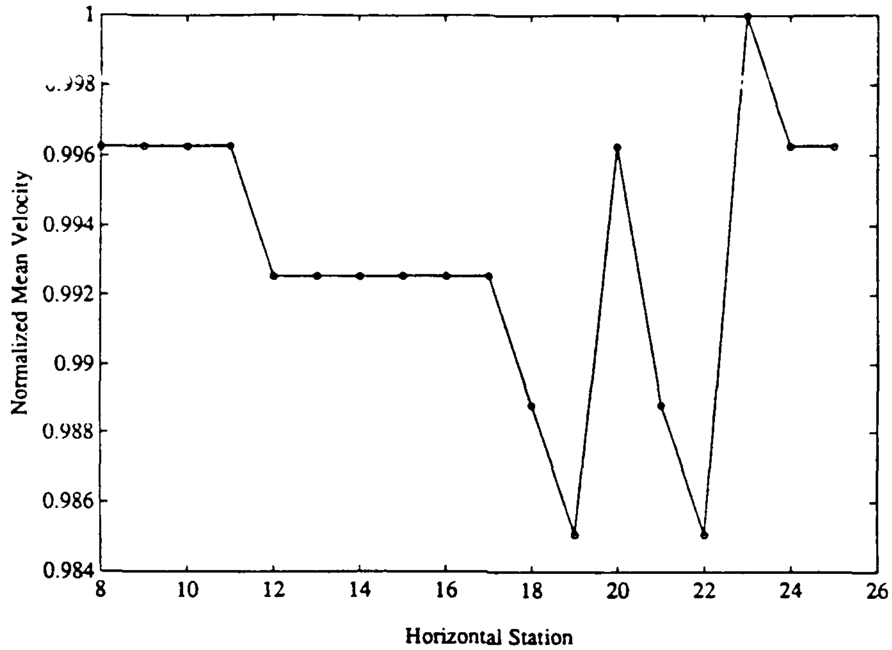

Figure 40. Station B, Velocity = 50 m/s, AoA = 24 degrees

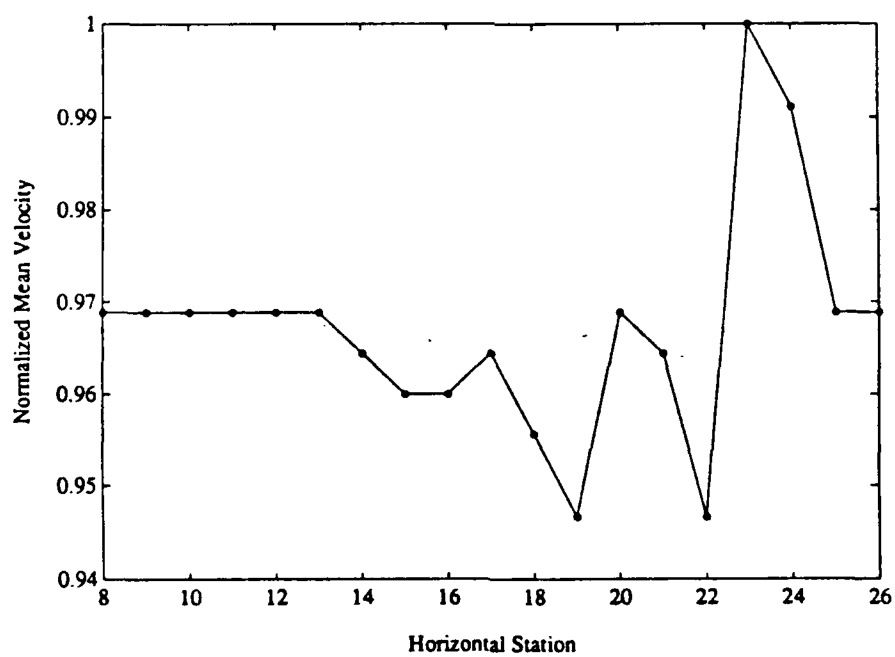

Figure 41. Station B, Velocity = 50 m/s, AoA = 25 degrees

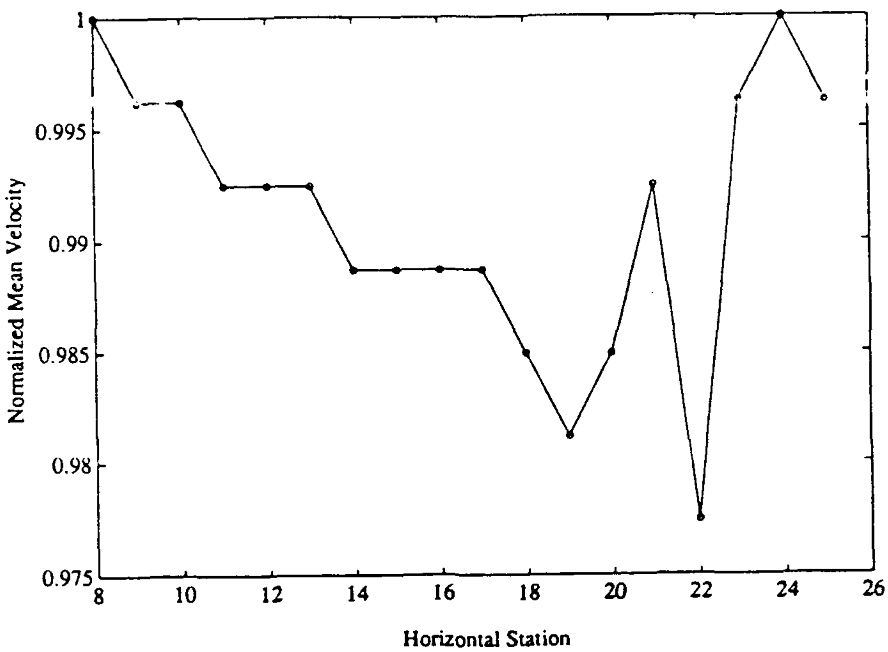

Figure 42. Station B, Velocity = 50 m/s, AoA = 26 degrees

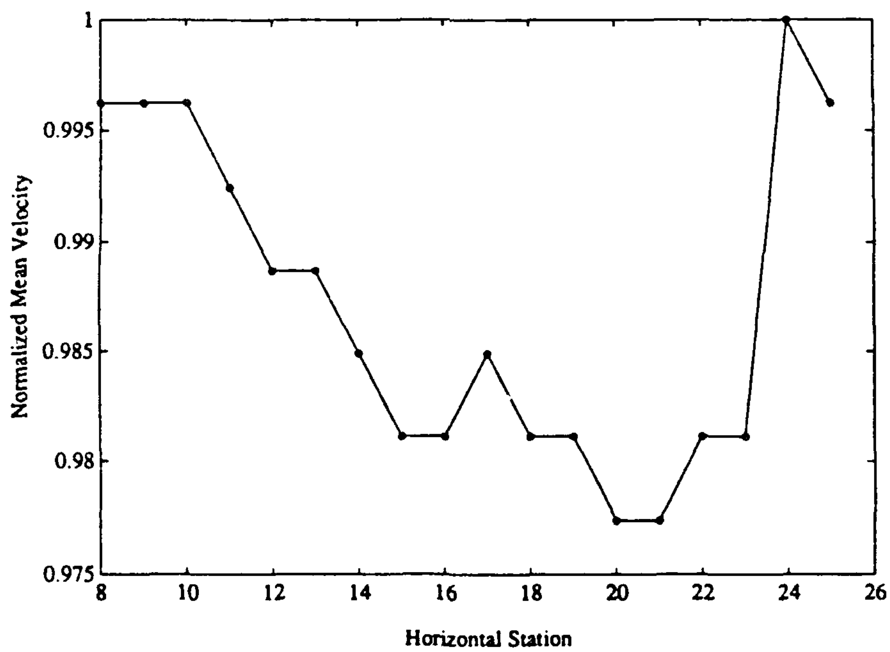

Figure 43. Station B, Velocity = 50 m/s, AoA = 28 degrees

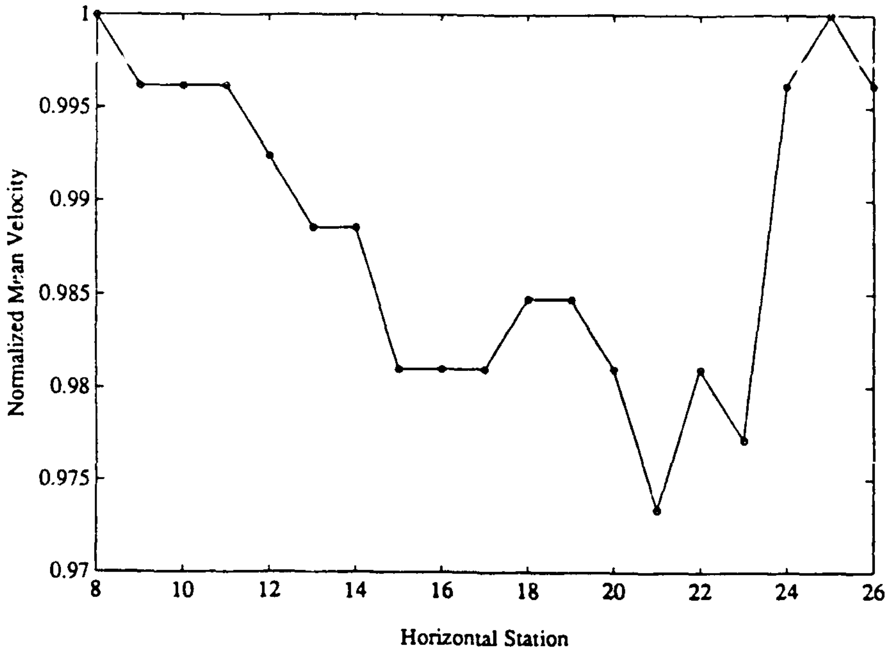

Figure 44. Station B, Velocity = 50 m/s, AoA = 30 degrees

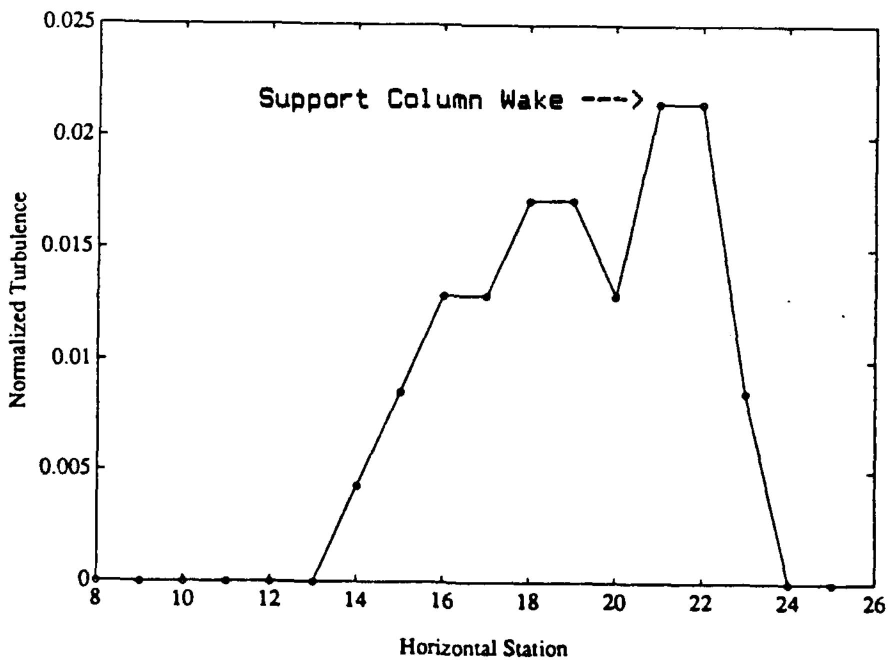

Figure 45. Station B, Velocity = 10 m/s, AoA = 25 degrees, No LEX Fence

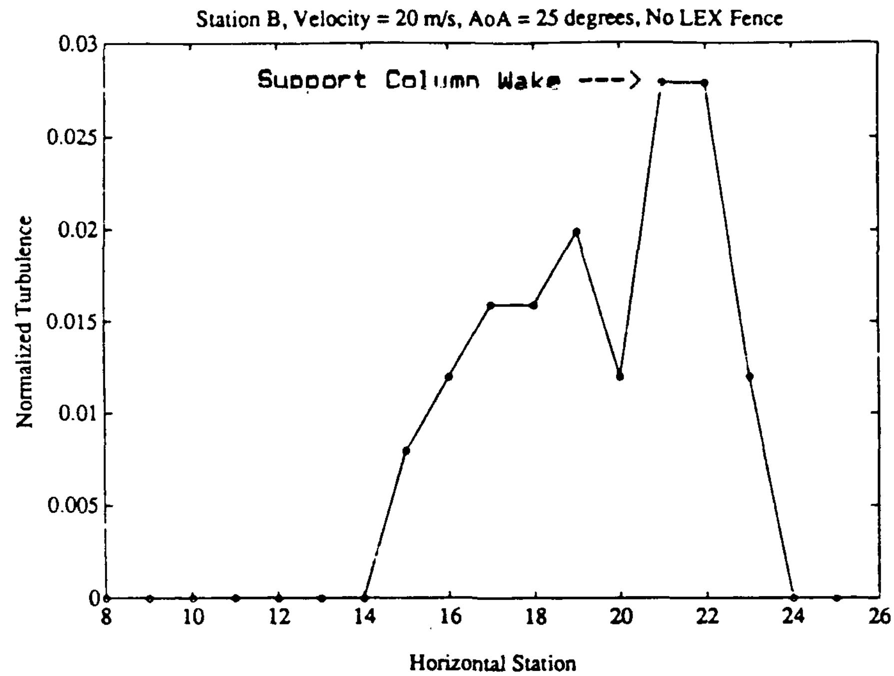

Figure 46. Station B, Velocity = 20 m/s, AoA = 25 degrees, No LEX Fence

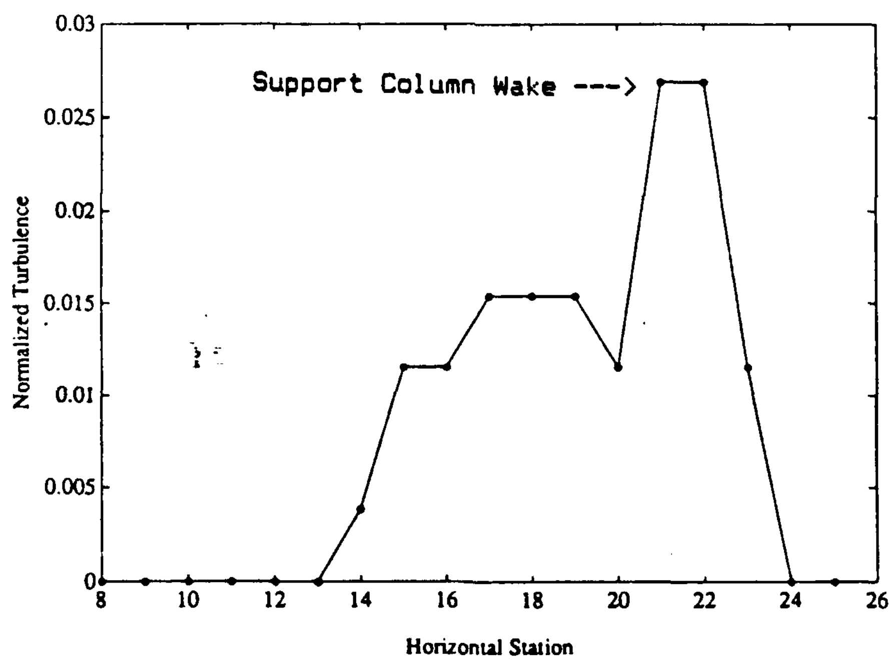

Figure 47. Station B, Velocity = 30 m/s, AoA = 25 degrees, No LEX Fence

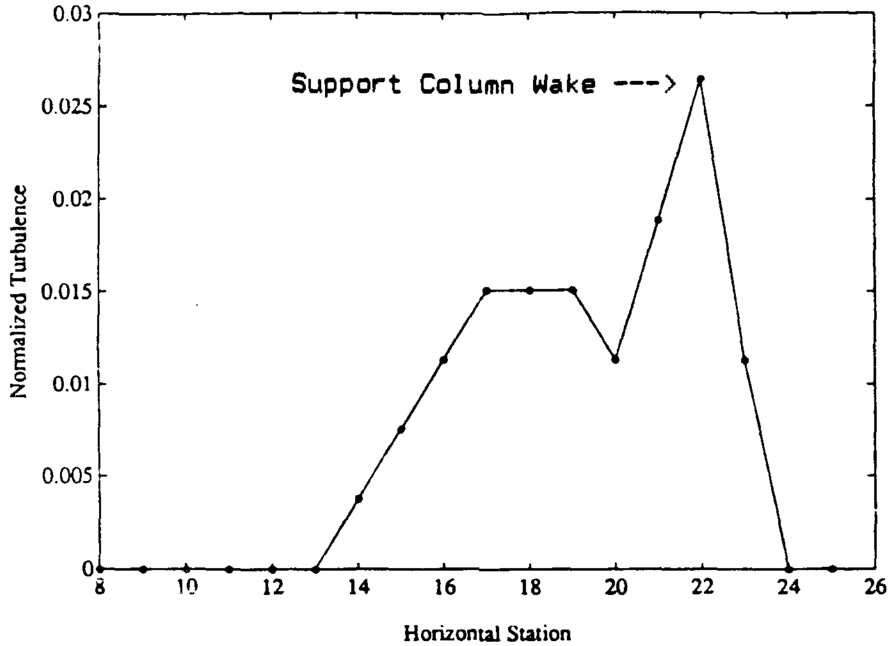

Figure 48. Station B, Velocity = 40 m/s, AoA = 25 degrees, No LEX Fence

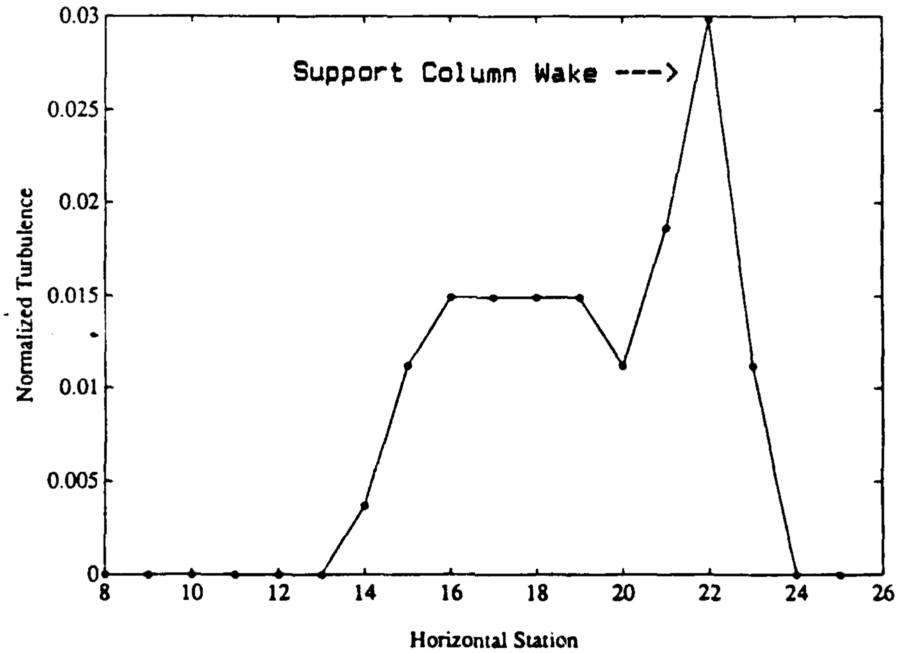

Figure 49. Station B, Velocity = 50 m/s, AoA = 25 degrees, No LEX Fence

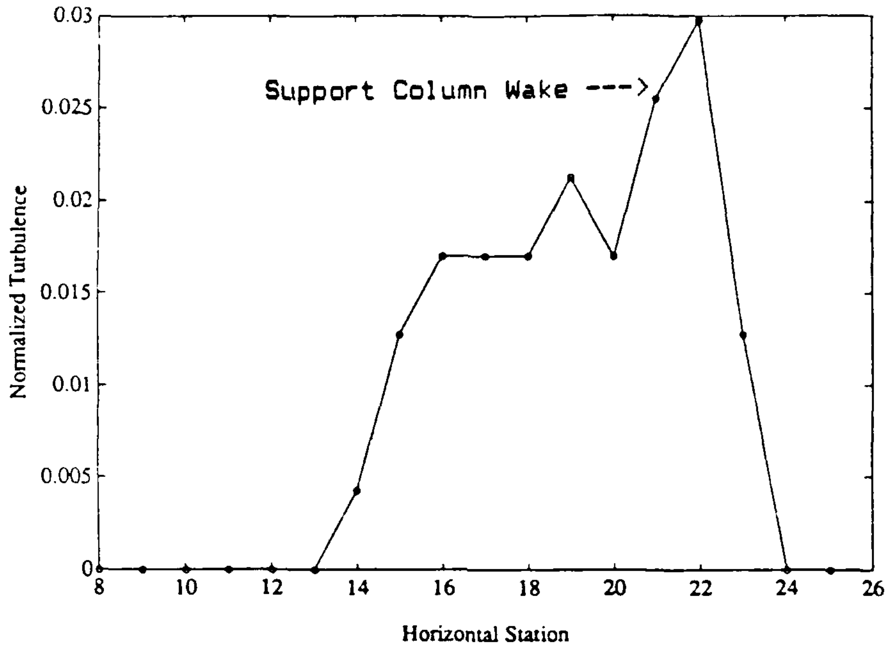

Figure 50. Station B, Velocity = 10 m/s, AoA = 25 degrees, With LEX Fence

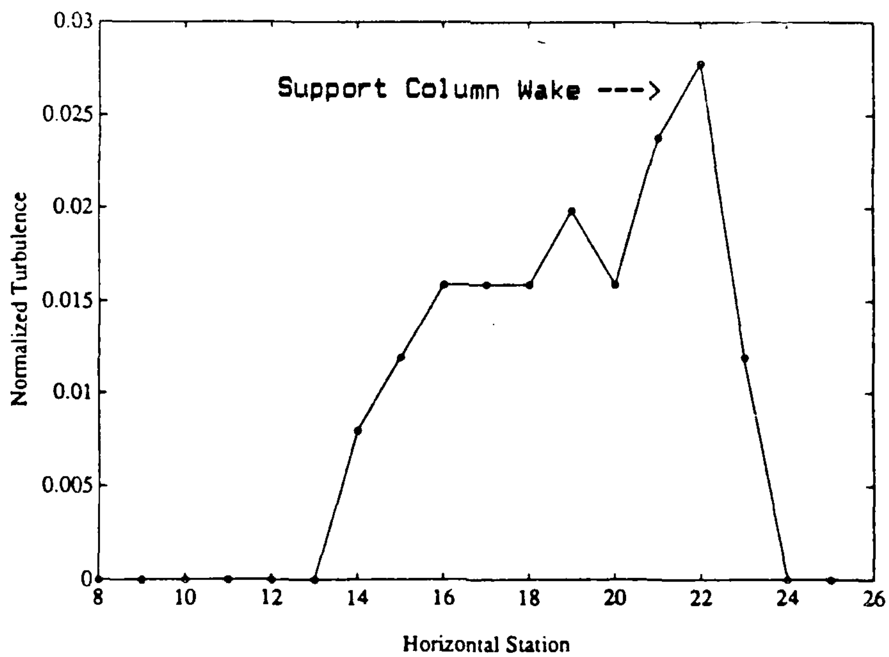

Figure 51. Station B, Velocity = 20 m/s, AoA = 25 degrees, With LEX Fence

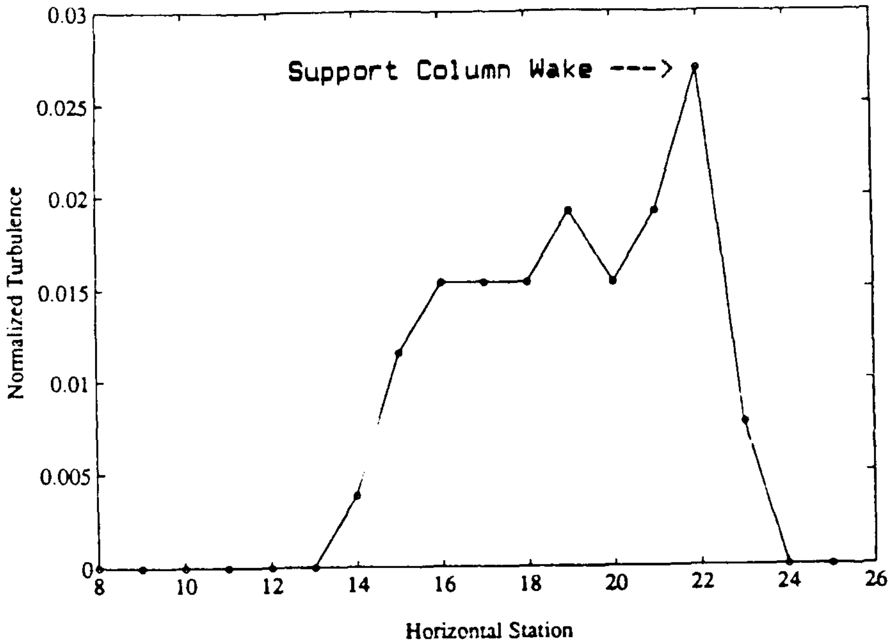

Figure 52. Station B, Velocity = 30 m/s, AoA = 25 degrees, With LEX Fence

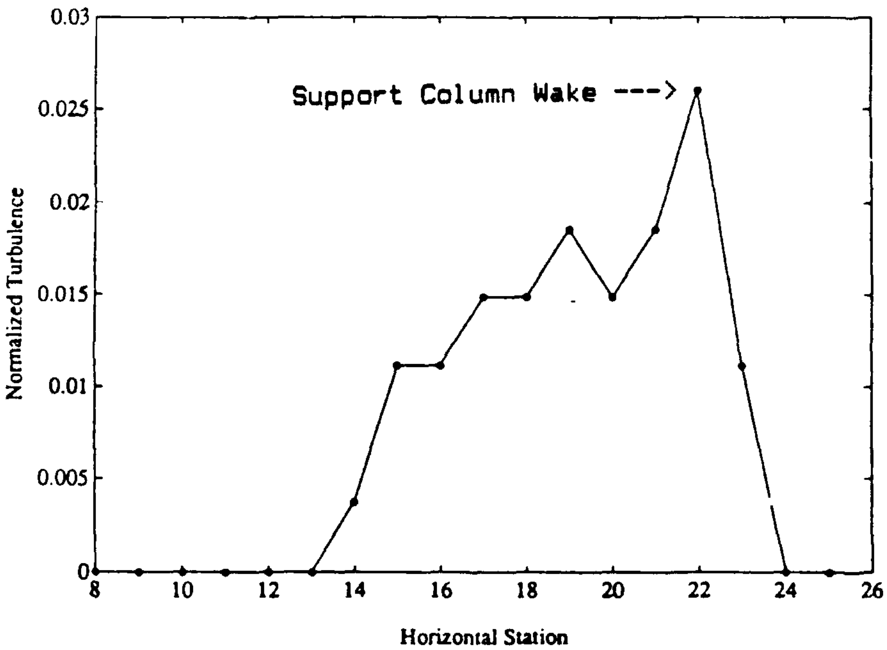

Figure 53. Station B, Velocity = 40 m/s, AoA = 25 degrees, With LEX Fence

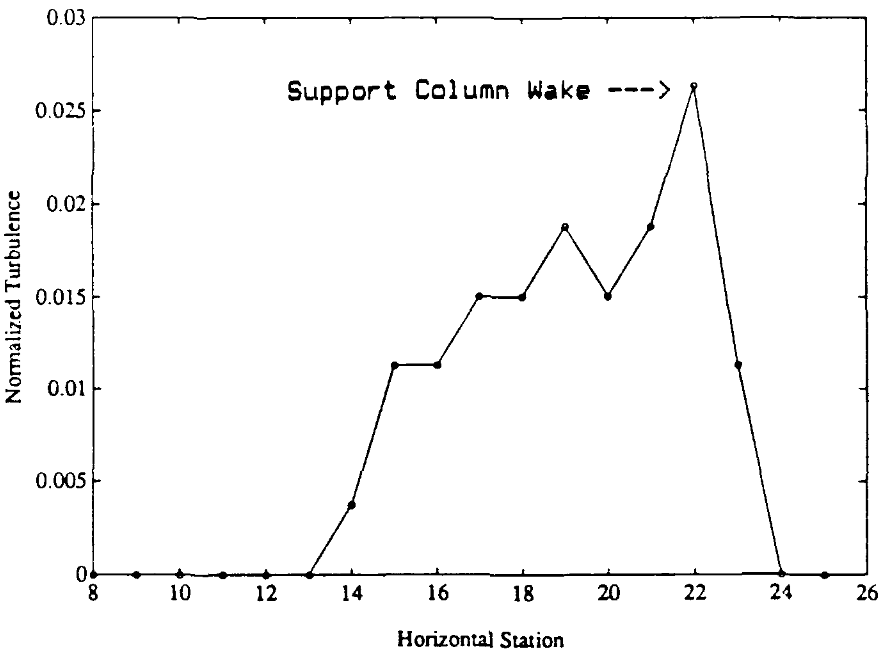

Figure 54. Station B, Velocity = 50 m/s, AoA = 25 degrees, With LEX Fence

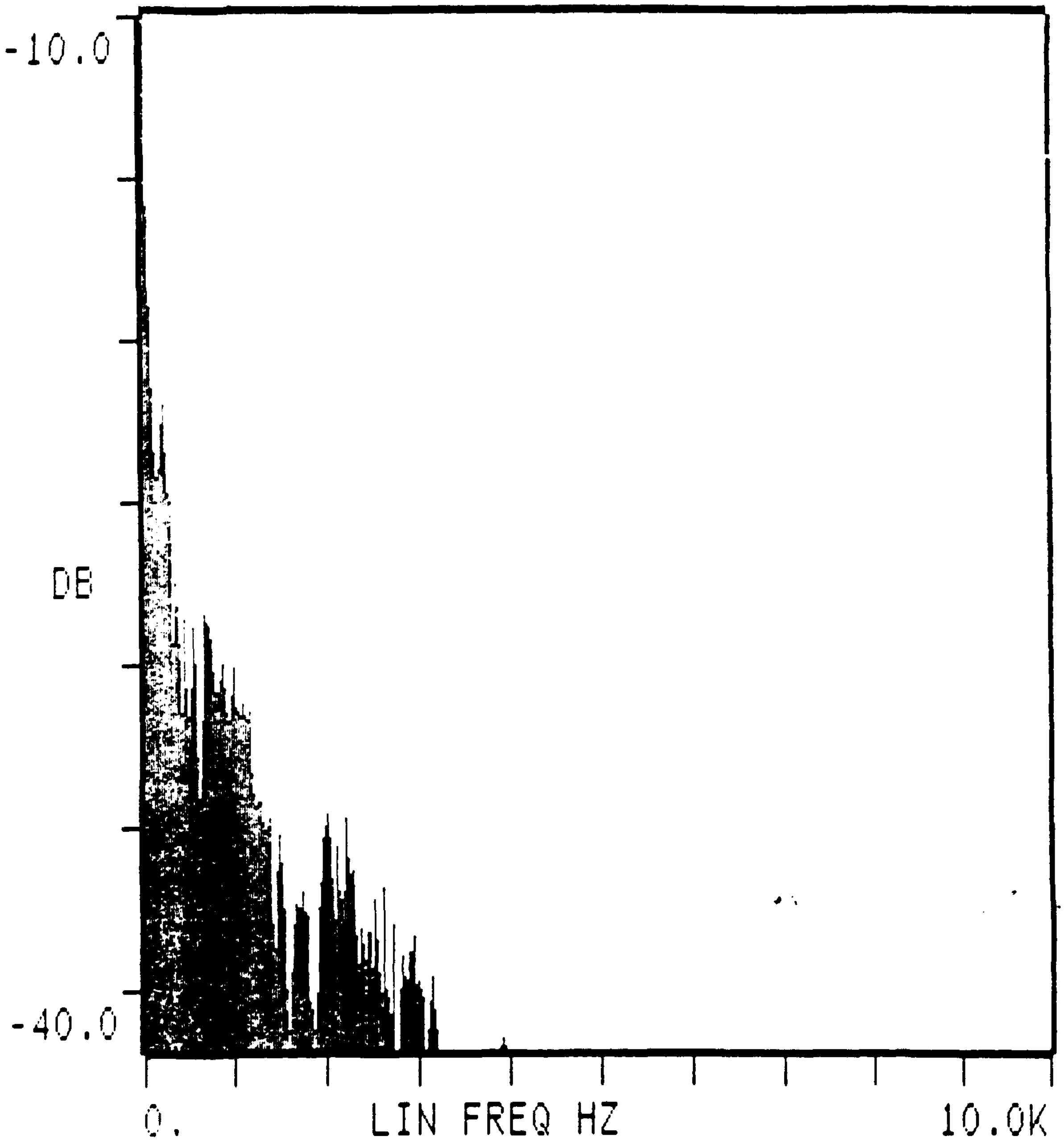

Figure 55. Station B, Velocity = 10 m/s, AoA = 25 degrees, No Lex Fence

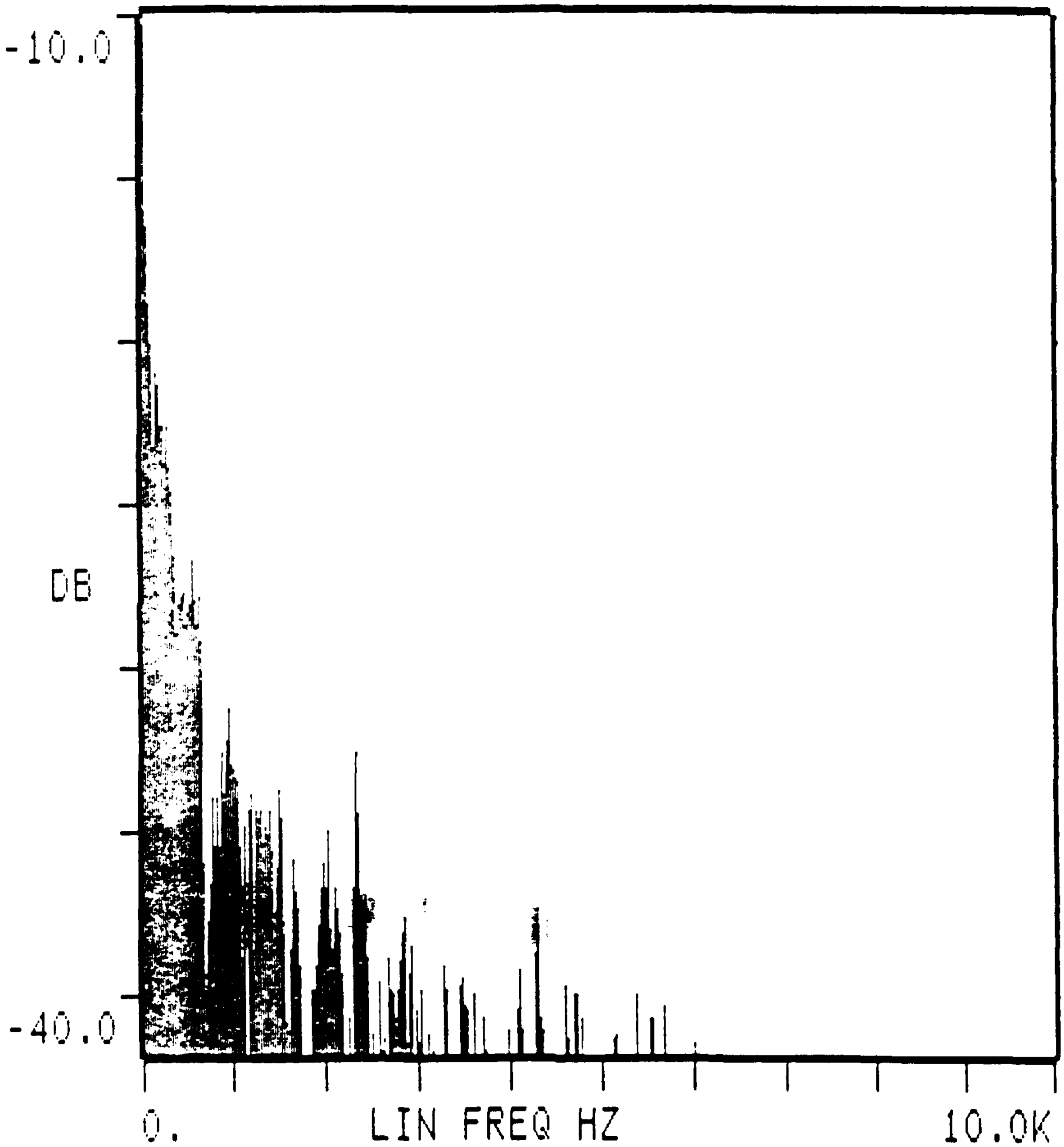

Figure 56. Station B, Velocity = 20 m/s, AoA = 25 degrees, No Lex Fence

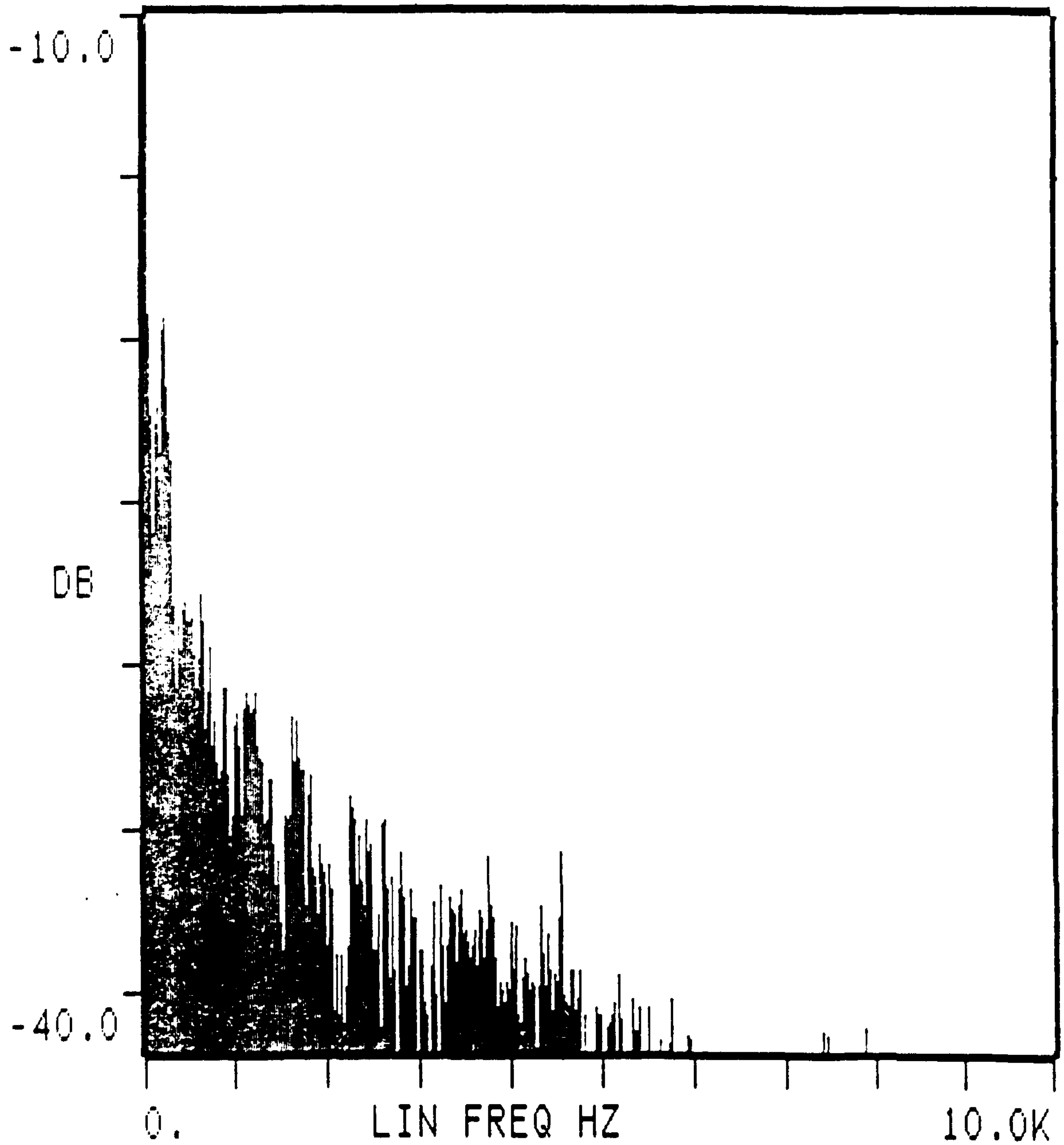

Figure 57. Station B, Velocity = 30 m/s, AoA = 25 degrees, No Lex Fence

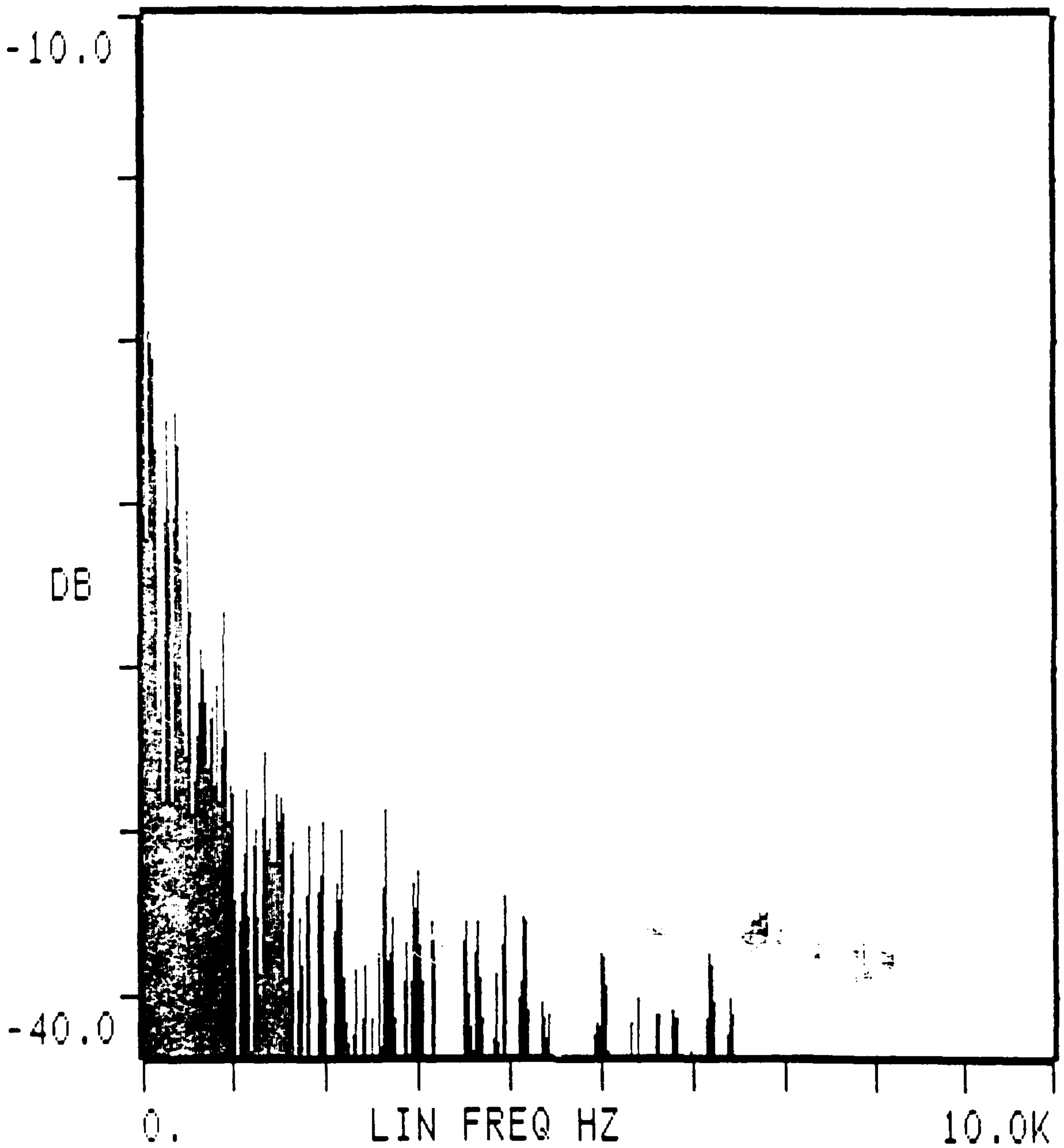

Figure 58. Station B, Velocity = 40 m/s, AoA = 25 degrees, No Lex Fence

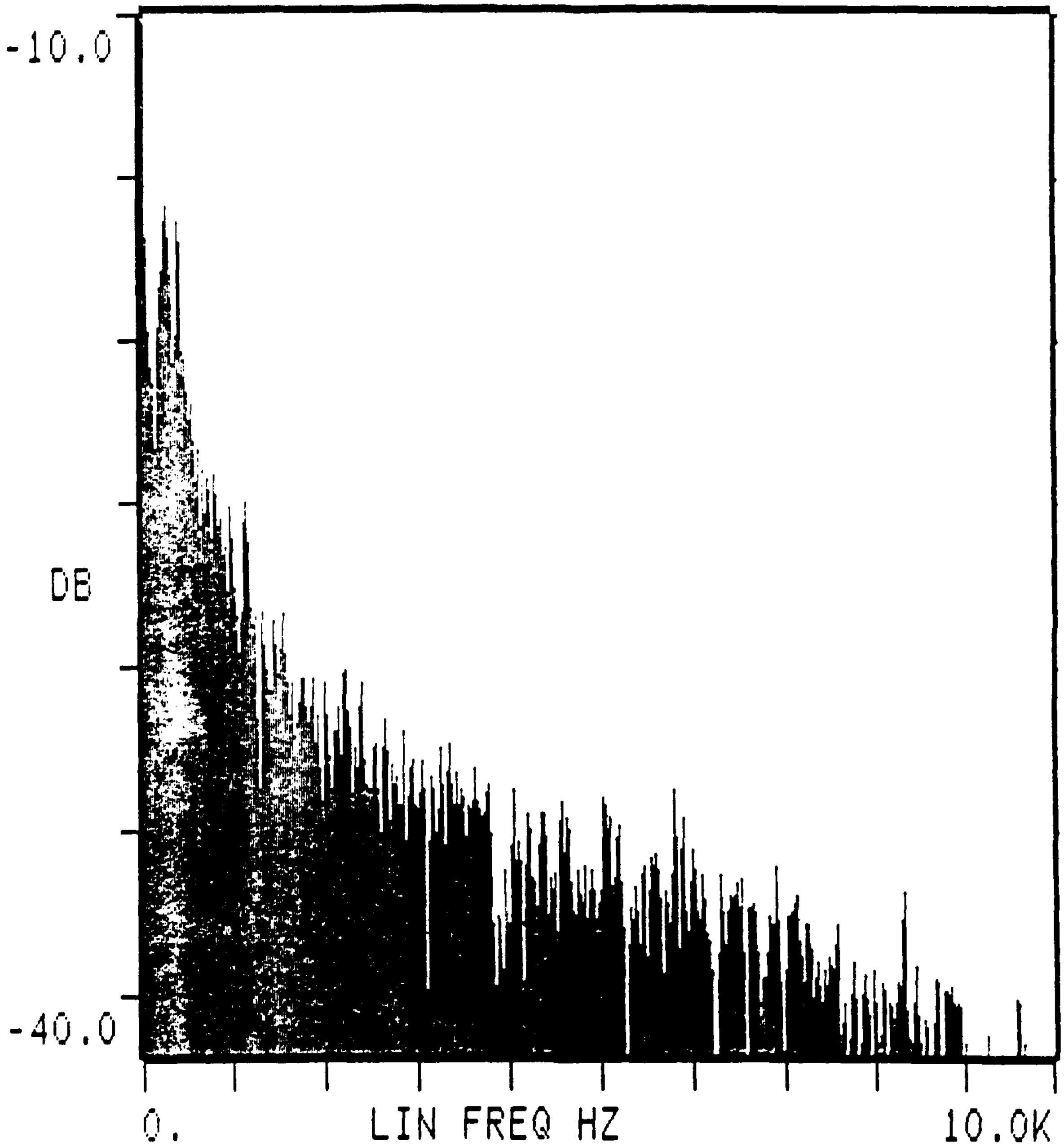

Figure 59. Station B, Velocity = 50 m/s, AoA = 25 degrees, No Lex Fence

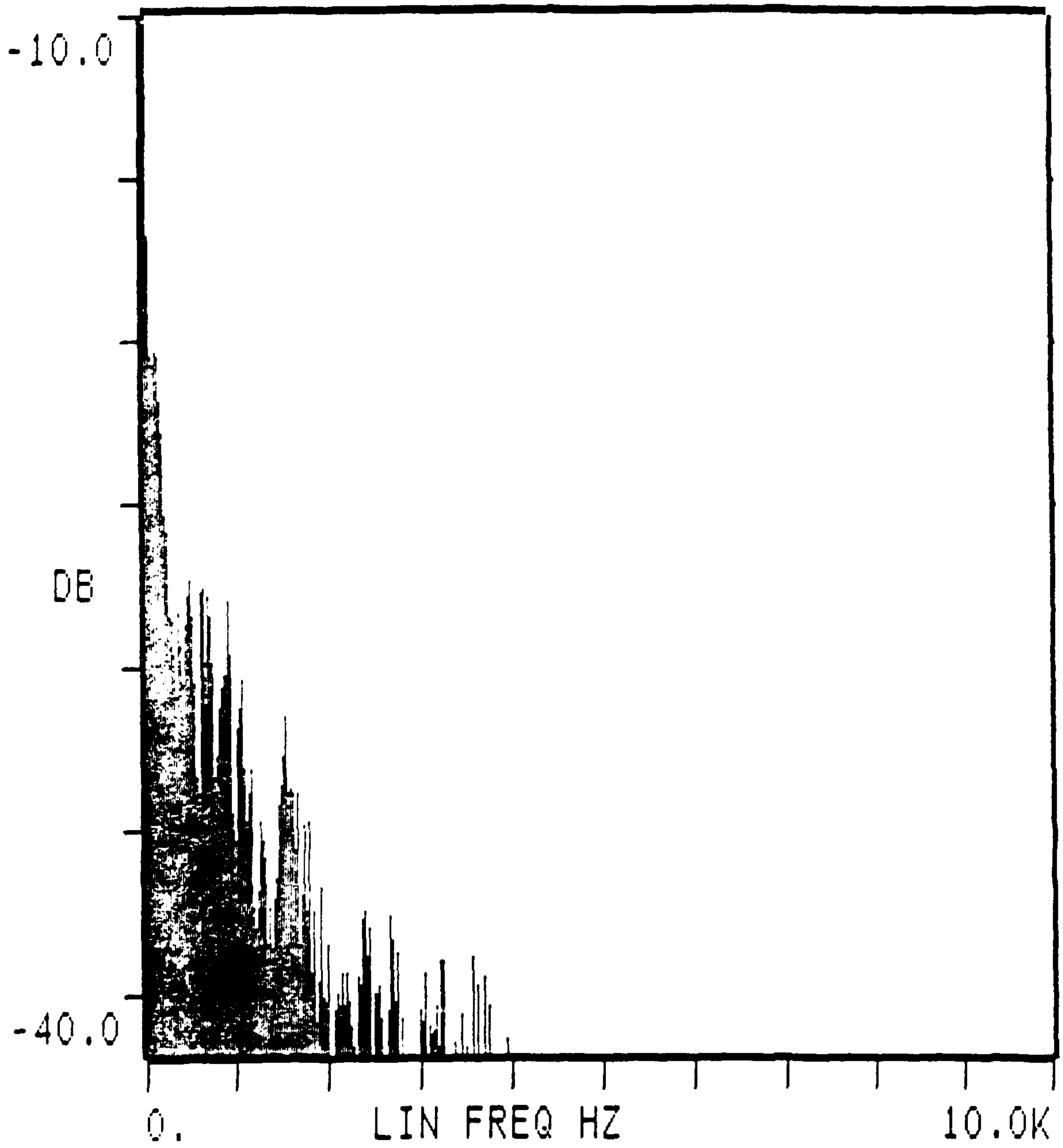

Figure 60. Station B, Velocity = 10 m/s, AoA = 25 degrees, With LEX Fence

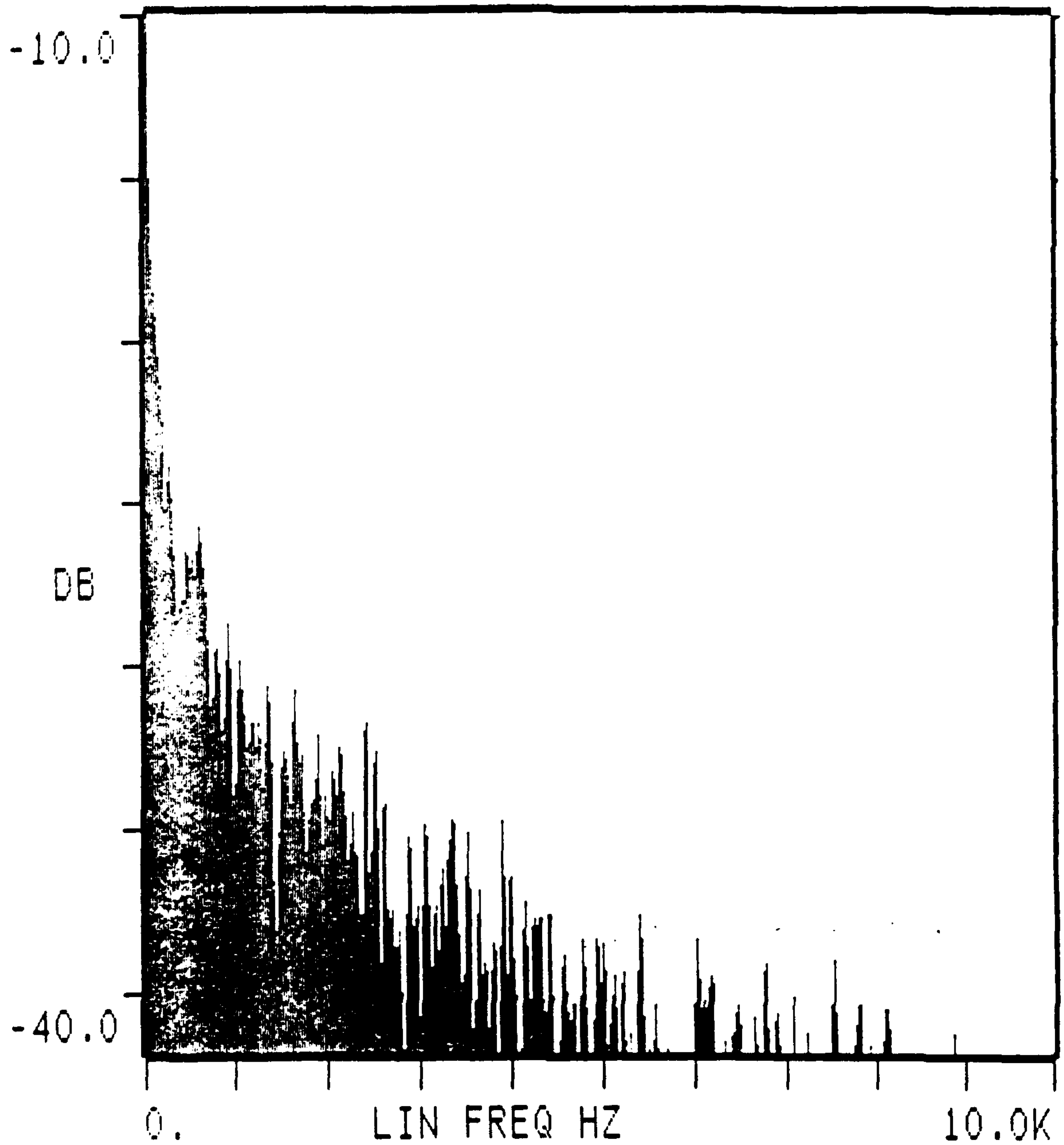

Figure 61. Station B, Velocity = 20 m/s, AoA = 25 degrees, With LEX Fence

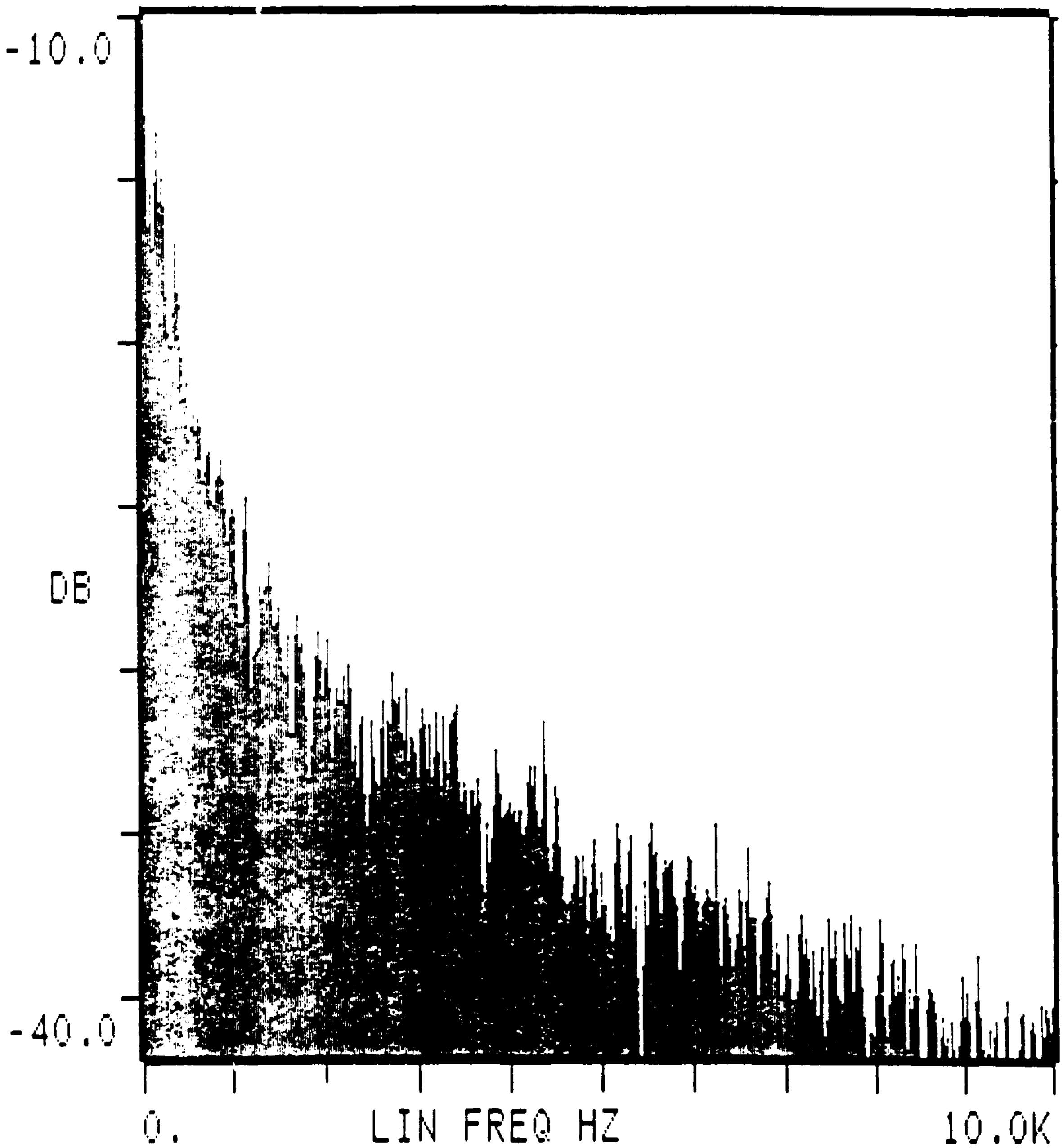

Figure 62. Station B, Velocity = 30 m/s, AoA = 25 degrees, With LEX Fence

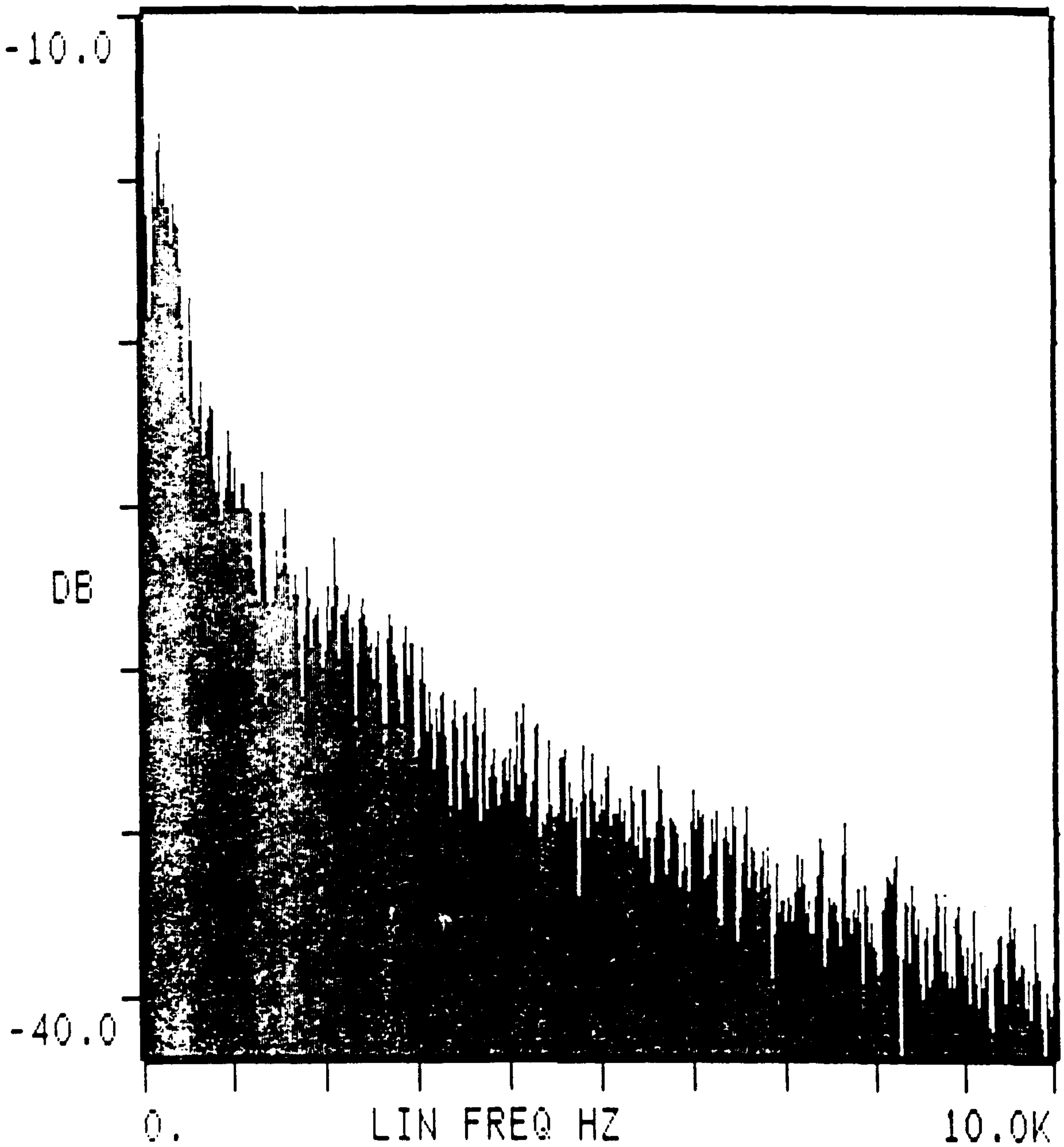

Figure 63. Station B, Velocity - 40 m/s, AoA - 25 degrees, With LEX Fence

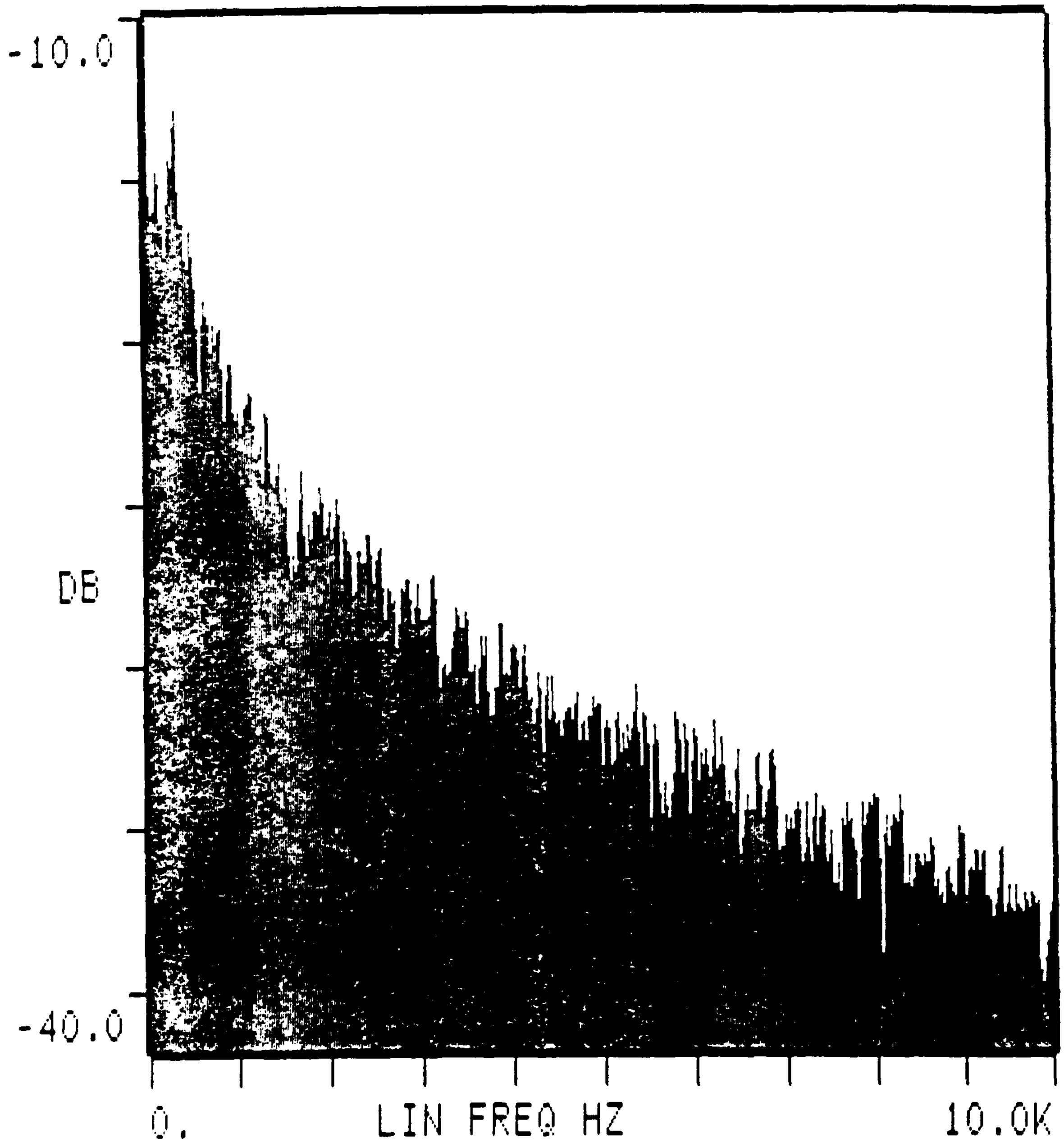

Figure 64. Station B, Velocity = 50 m/s, AoA = 25 degrees, With LEX Fence

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